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Soils Report from 2007

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Contents

Executive Summary

Countryside Survey is a unique study or 'audit' of the natural resources of the UK's countryside. The Survey has been carried out at regular intervals since 1978. The countryside is sampled and studied using rigorous scientific methods, allowing us to compare results from 2007 with those from previous surveys. In this way we can detect the gradual and subtle changes that occur in the countryside over time. A series of reports have been published outlining the main findings for UK and individual countries which included results for two soil variables namely soil carbon and acidity. This report outlines the major findings for all soil variables measured as part of the survey in 2007.

Key policy questions to be answered in 2007 were:

- Can we confirm the loss of soil carbon (0-15cm) as reported by Bellamy *et al*. 2005?
- Has the recovery from acidification detected by Countryside Survey in 1998 between 1978 and 1998 continued?
- Can the trend of eutrophication of the countryside detected in the vegetation be detected in the soil using the mean total nitrogen concentration?
- Can the trend of eutrophication of the countryside detected in the vegetation be detected in the soil as well using a more sensitive soil process method for nitrogen?
- Can the trend of increasing P status in intensive grasslands be confirmed and is it matched in other habitats?
- Is the decline in atmospheric deposition of heavy metals as reported by the Heavy Metals Monitoring Network reflected in soil metal concentrations measured in Countryside Survey?
- Does Countryside Survey provide any evidence to indicate that there has been a loss of soil biodiversity as has been stated by the European Union?

Soils have been part of Countryside Survey since it's inception in 1978. The rationale for their inclusion was originally to provide many of the explanatory variables which contribute to the understanding of vegetation distribution and change which are the central core of the survey. More recently soils have been recognised as a valuable resource in their own right due to their importance for delivering a range of ecosystem services. Consequently the number of variables have increased over time from soil organic matter and pH in 1978, to nutrients, contaminants and biodiversity in 1998, and soil physical measurements and biogeochemical fluxes in the latest survey in 2007.

The soil variables were selected for inclusion in the 2007 survey according to a range of criteria including: relevance to policy needs, scientific questions, uniqueness of Countryside Survey soils data both in isolation and when combined with other Countryside Survey variables, value for money and links and compatibility with other soil monitoring programmes. It should be noted that with the exception of soil invertebrates many Countryside Survey soil variables are currently included in the list of recommended primary indicators of soil quality by the UK Soil Indicator Consortium namely: soil organic matter, soil organic carbon, bulk density, soil acidity (pH), mean total nitrogen concentration, an indicator of phosphorus availability (Olsen-P), an indicator of nitrogen availability (mineralisable-N), total copper, zinc, cadmium and nickel. All variables with the exception of soil invertebrates are measured in the top 15cm of the soil profile only. Soil invertebrates are recorded for the top 8cm of soil. This focus on the top 15cm of soil mirrors the focus of several other soil monitoring programmes as it is thought the top soil horizons are the most susceptible to change over time as they are more immediately affected by land management activities and environmental change. Ideally future soil monitoring should include lower soil horizons as important stocks of carbon, supply of nutrients, filtering and storage of contaminants, and soil biota occur below the top 15cm.

Countryside Survey uses a sampling approach which samples one-kilometre squares randomly located within different land class in GB. The original 1978 survey consisted of 256 1-km squares and collected five soil samples per square where possible, taken from random co-ordinates in five segments of the square. Detailed vegetation and other biophysical measurements were taken at the same location. In total, the 1978 survey collected 1197 soil samples for analysis. During 1998, surveyors collected soil samples from the plots used for soil sampling in the original 1978 squares and 1098 samples were returned for analysis. Plots were re-located using maps and/or markers placed in the 1978 survey. In 2007, 591 1-km squares were sampled with a total of 2614 samples returned for analysis. More samples were therefore taken in 2007 than collectively in 1978 and 1998. This increase in sample over time has been driven by the requirement to provide individual country level reports first for Scotland in 1998 and then Wales in 2007. Statistical methods are used to enable this increase in sample number over time to be taken into account when estimating change over time. The limited number of sampling sites in Wales in 1978 and 1998 have limited the number of vegetation and soil categories where change can be reported. However, the data provides an important expanded baseline for reporting a wider range of changes in future surveys.

Full details on all methods used are available from the Countryside Survey website (Emmett *et al.* 2008; available at: http://www.countrysidesurvey.org.uk/pdf/reports2007/CS_UK_2007_TR3.pdf)

Results are reported by three major categories for Great Britain and individual countries:

- Broad Habitat - The Broad Habitat classification consists of 27 habitats which account for the entire land surface of Great Britain, and the surrounding sea. Countryside Survey reports on soils for 10 major terrestrial habitats.
- Aggregate Vegetation Class (AVC) – is a high level grouping of vegetation types produced from a quantitative hierarchical classification of the different plant species found in the original Countryside Survey sample plots.
- Soil organic matter category - Mineral, humus mineral, organo-mineral and organic soils.

Significant results relate to statistical significance with their ecological and policy relevance highlighted where appropriate.

Key findings from the soils component of the Countryside Survey in 2007 are:

Bulk Density

- A total of 2614 samples were sampled from 591 1km squares from across Great Britain during the Countryside Survey field survey in 2007.
- Topsoil bulk density measurements were carried out on all individual samples collected in 2007. Values ranged from 0.02 to 1.95 g cm^{-3}, and were negatively correlated with soil C concentration. Mineral soils exhibited the highest bulk density values and organic soils the lowest. Average topsoil bulk density across Aggregate Vegetation Class and Broad Habitat classes varied between 0.2 and 1.2 g cm^{-3} and was lowest in Bog soils and highest in Arable and Horticulture soils.
- A new transfer function between bulk density and %C has been defined which significantly changes past estimates of soil carbon densities and stocks (0-15cm) of organic soils previously published for other surveys.

Carbon

- Carbon concentration in the soil (0-15 cm) increased in Great Britain between 1978 and 1998, and decreased between 1998 and 2007. Overall there was no change in carbon concentration in the soil (0-15 cm) in Great Britain between 1978 and 2007 and cannot confirm the loss reported by the National Soil Inventory.
- The one consistent exception is loss of carbon (0-15cm) from the intensively managed Arable and Horticulture Broad Habitat / Crops and Weeds Aggregate Vegetation Class. This suggests that current policies in place to limit soil degradation are not maintaining soil quality in cropped land.
- The mean soil (0-15cm) carbon density across Great Britain in 2007 was calculated to be 69 t/ha, ranging between a mean of 47 t/ha in the Arable and Horticulture Broad Habitat to a mean of 91 t/ha in Acid Grassland. Peat soils do not contain the highest density in topsoil due to low bulk densities. The new transfer function between bulk density and %C significantly changes past estimates of soil carbon densities, stocks and change (0-15cm) of organic soils previously published for other surveys.

- Area estimates for each Broad Habitat were used to convert soil carbon densities to soil (0-15cm) carbon stock for GB and individual countries. Soil (0-15cm) values were 1582 TgC for GB and 795TgC, 628 TgC and 159 TgC for England, Scotland and Wales in 2007 respectively. It must be emphasised this significantly underestimates the total carbon stock in soils due to the large carbon stores at depth particularly in peat soils. This has greatest impact for estimates for Scotland. However, topsoil carbon stocks may be most vulnerable to land management activities and environmental change.

pH

- The mean pH of soils (0-15cm) increased in less acidic soils across Great Britain (GB) between 1998 and 2007 continuing a trend observed between 1978 and 1998. These soils are associated with Broadleaved Woodland, Arable and Horticulture, Improved Grassland and Neutral Grassland Broad Habitats. This increase in pH is consistent with the expected benefit of continued reductions in sulphur emissions.
- There was no significant change in mean soil (0-15 cm) pH in more acidic, organic-rich soils across Great Britain between 1998 and 2007. This will affect Broad Habitats such as Bog, Dwarf Shrub Heath and Acid Grassland. Data analysis is ongoing to determine if the lower sulphur reductions in the north and west of the Great Britain or other drivers of change such as nitrogen deposition and land management are responsible in the organic soils where pH did not significantly increase between 1998 and 2007. Conversion between land uses between surveys was not responsible for this as similar trends were observed in soils with or without conversion.
- One exception with no apparent trends between any time period was Coniferous Woodland. It is possible the acidification of soils associated with intensive forestry due to base cation uptake and enhanced capture of acidic pollutants by the tree canopy may be offsetting the effects of reduced sulphur emissions.
- The results for individual countries broadly reflected those for Great Britain as a whole with continued increase in soil pH only observed in less acidic soils. Insufficient sample size for some habitat types with lower area in individual countries prevented significant trends being identified in some cases.
- The implications of these findings are that current emission control policies combined with current policies to protect soil through sustainable land management practices have had some major benefits but they may not be sufficient to promote continued recovery from acidification in organic-rich soils.

Nitrogen

- There were small but significant decreases in mean soil (0-15 cm) total nitrogen concentration between 1998 and 2007 in many Broad Habitats and Aggregate Vegetation Classes across Great Britain and the individual countries; no reporting category recorded an increase in mean soil (0-15 cm) total nitrogen concentration.
- For semi-natural and woodland soils continued input of nitrogen deposition at 20-30 kgN/ha/yr for many parts of Great Britain has not caused the expected average increase of 3-4% in this basic soil property. Instead, the decreases observed combined with a trend for an increase in total carbon to nitrogen ratio suggest there may be increased nitrogen loss or uptake possibly combined with a trend for increased carbon density as reported for some soils in Chapter 2. The effects of one or both of these processes would be to effectively ‘dilute’ the soil (0-15cm) nitrogen concentration signal. Both processes (increased nitrogen loss and increased carbon fixation by plants leading to storage in soil) are known possible consequences of nitrogen enrichment which can result in vegetation composition change and thus this parameter may not be a sensitive indicator of eutrophication from atmospheric nitrogen deposition.
- There was no change or a small significant decline in mean soil total nitrogen concentrations in improved and fertile grassland categories between 1998 and 2007 across Great Britain and within individual countries despite major reductions in fertiliser use. As there is no change in the soil (0-15cm) total carbon to nitrogen ratio this indicates farmers have maintained soil nitrogen status in managed grassland systems despite a reduction in mineral fertiliser use possibly due to use of alternative organic sources of nitrogen such as slurry and organic waste products.

- In cropland systems, a significant decline in soil (0-15cm) total nitrogen concentrations and total carbon to nitrogen ratios was observed between 1998 and 2007 for Great Britain and England. A significant decline in soil (0-15cm) total carbon concentrations was also reported (Chapter 2). As there is only a small decline in fertiliser use in these systems and there is evidence of combined carbon and nitrogen loss, deep ploughing, erosion or increased decomposition rates may be the most likely explanation of this trend.

Mineralisable-N

- Mineralisable-N stock (kgN / ha) in soil (0-15cm) was a sensitive indicator of recognised differences in nitrogen availability between different vegetation types suggesting it is a promising indicator of eutrophication of the countryside.
- Initial investigations testing the link between mineralisable-N and occurrence of plant species in 45 test sites suggests it provides additional information to mean total nitrogen concentration data (%N) possibly linked to short term changes in nitrogen availability or specific vegetation or soil types.
- There were strong geographical trends in the proportion of mineralised-N transformed to the mobile form, nitrate, which suggest a close relationship to broad-scale climatic or soil parameters.
- Future analyses will separate out the inherent variability associated with climate, vegetation and soil type to identify spatial patterns which can be linked to atmospheric deposition and changes in management.

Olsen-P

- Mean Olsen-P concentrations in soil (0-15cm) is an index of the fertility of agricultural soils. It's use and relevance in semi-natural and organic soils is less certain. Soils collected during Countryside Survey in 1998 and 2007 indicated there had been a significant decrease in Olsen-P concentrations in soil (0-15cm) in most Broad Habitats or Aggregate Vegetation Classes across Great Britain and within individual countries.
- Olsen-P concentrations in soil (0-15cm) decreased significantly in all soil organic matter categories across Great Britain and within individual countries between 1998 and 2007 apart from humus-mineral soils in Scotland where no change was observed.
- The data do not confirm a trend of increasing P status in intensive grasslands or any other habitat soils (0-15cm) but indicate a loss of available phosphorus between 1998 and 2007 across a wide range of habitats and soil types. This is likely to be linked to the large reductions in phosphorus fertiliser use over the same period.

Metals

- A comparison of back corrected Countryside Survey soils (0-15cm) analyses for 1998 and 2007 samples indicated that, as would be expected, only relative small changes in soil trace metal concentrations occurred between surveys despite reported declines in atmospheric deposition due to the long residence time of metals in soils.
- Of seven metals for which repeat measurement were made during the 2007 survey, only for one, Cu, was a statistically significant difference in soil (0-15cm) concentrations (an increase) found at the GB level.
- When the data for repeat metal measurements were stratified by Broad Habitat, Aggregate Vegetation Class and soil organic matter category, further statistically significant differences were seen. For Cu generally significant increases were observed whilst for two metals, Cd and Pb, changes were small and idiosyncratic between stratifications. For three metals, Cr, Ni, Zn, changes were generally characterised by reduction in crop lands and no change or slight increases in less managed habitats.
- For some metals, such as Cu and Cd it is likely that additional sources (animal manures and possibly sewage sludge, manures and compost for Cu and fertiliser for Cd) beyond atmospheric inputs are important in maintaining or even increasing soil concentrations principally in managed areas. For the remaining metals, especially Cr, Ni and Zn, there is some suggestion that in areas where cropping takes place, output fluxes may now exceed inputs enabling soil concentrations to decline.

- Managed landscape where intensive cropping takes place, but sewage sludge, animal manures and composts are rarely applied, may be among the first habitats to return from their slight-moderately elevated states to their pre-industrial background concentrations and could be a focus for future monitoring.

Soil Invertebrates

- There were an estimated 12.8 quadrillion (1.28x10^{16}) soil invertebrates present in the top 8 cm of Great Britain soils during the time of Countryside Survey sampling in 2007. Comparing these results with those from the survey in 1998 has enable change in soil biodiversity to be estimated at a national scale.
- A significant increase in total invertebrate catch in samples from soils (0-8cm) from all Broad Habitats, Aggregate Vegetation Classes and soil organic matter categories, except for agricultural areas on mineral soils, was found in Countryside Survey in 2007. The increase in invertebrate catch was mainly the result of an increase in the catch of mites in 2007 samples. This resulted in an increase in the mite: springtail ratio, but a decreased Shannon diversity due to the dominance of mites in Countryside Survey in 2007 cores.
- A small reduction in the number of soil invertebrate broad taxa (0-8cm) was recorded which is not inconsistent with reported declines in soil biodiversity. However, repeat sampling is required to ensure this is not linked to different seasonal conditions in the two sampling years. Further analysis through focussed study may be needed to assess whether the changes in soil chemistry, land management annual weather patterns or merely natural population variation can explain observed soil invertebrate community changes.

Preliminary results from the soils work were presented in the Countryside Survey UK Results from 2007 report (Carey *et al*. 2008 a,b) and the country Reports published for England, Scotland and Wales in 2009 (***http://www.countrysidesurvey.org.uk/reports2007.html***).

Data for the Countryside Survey in 2007 and earlier years have previously been released via the project web site (***http://www.countrysidesurvey.org.uk/data.html***).

The policy implications of trends observed are outlined in each chapter of the report together with a discussion of possible causes of the changes observed. Ongoing data analysis is focussed on identifying the links between soil variables measured, between soil and vegetation and water quality changes reported in other Countryside Survey reports, and between trends in soil variables and the intended and unintended change of our environment from man's activities such as land use and management, air pollution and climate change. A subset of the results from these analyses will be reported in the Countryside Survey Integrated Assessment Report later in 2010 with the remainder in the scientific peer-review literature.

1. Field sampling and Bulk Density

Summary

- **A total of 2614 samples were collected from 591 1km squares across GB during the CS field survey in 2007**
- **Topsoil bulk density measurements were carried out on all individual samples collected in 2007. Values ranged from 0.02 to 1.95 g cm^{-3}, and were negatively correlated with soil C concentration. Mineral soils exhibited the highest bulk density values and organic soils the lowest. Average topsoil bulk density across Aggregate Vegetation Class and Broad Habitat classes varied between 0.2 and 1.2 g cm^{-3} and was lowest in bog soils and highest in arable and horticultural soils**
- **A new transfer function between bulk density and %C has been defined which significantly changes past estimates of soil carbon densities and stocks (0-15cm) of organic soils previously published for other surveys.**

1.1 Introduction

Countryside Survey (CS) is an integrated survey of the GB countryside and soils have been part of CS since its inception in 1978. The rationale for their inclusion was originally to provide many of the explanatory variables which contribute to the understanding of vegetation distribution and change which are the central core of the survey.

The sampling strategy used for CS is based on a rigorous, statistical approach as an audit of the entire GB countryside combining monitoring of habitat, vegetation, soils and waters would be prohibitively expensive and impractical to run. CS uses a sample based approach, to collect information at the level of detail required for national reporting whilst providing the benefits of integrated monitoring. It is important to remember that the results of CS are therefore calculated *estimates* and not absolute numbers derived from a complete coverage of the country.

Great Britain was stratified first into Land Classes based on the major environmental gradients across the countryside. This permitted the sample to be structured to give reliable national statistics and also ensured that the sample is representative of the range of different environments found in Great Britain (England, Scotland and Wales). The sample consists of a set of 'sample squares' measuring 1km x 1km, selected randomly from the Ordnance Survey grid within the various Land Classes. Altogether, 591 sample squares were surveyed in 2007; 289 were in England, 107 in Wales, and 195 in Scotland. Sufficient sample squares were selected from each geographical region, to enable reliable statistical reporting for Great Britain as a whole and for each separate country (***Table 1.1***). As far as possible, the same squares are resampled each time CS is repeated, but in addition each successive CS has included greater numbers of sample squares. The estimates of change presented in this report use a statistical modelling technique to infer missing values so that changes between each year of the survey can be made using the maximum data available - see the CS Statistical report (Scott 2008). For full information about CS and methodology employed in square and plot selection and the field survey see the main GB report (Carey *et al.,* 2008, available at http://www.countrysidesurvey.org.uk/reports2007.html)

Table 1.1: Number of squares surveyed in each survey year which included soil sampling in each country of GB.

Country	1978	1998	2007
England	126	302	289
Scotland	108	203	195
Wales	22	64	107
Total	256	569	591

The soil variables were selected for inclusion in the 2007 survey according to a range of criteria including; relevance to policy needs, scientific questions, uniqueness of CS soils data both in isolation and when combined with other CS variables, value for money and links and compatibility with other soil monitoring programmes. It should be noted that with the exception of soil invertebrates, many CS soil variables are currently included in the list of recommended primary indicators of soil quality by the UK Soil Indicator Consortium namely: soil organic matter (LOI) and soil organic carbon, bulk density, soil acidity (pH), total-N (%N), an indicator of phosphorus availabilty (Olsen-P), an indicator of nitrogen availability (mineralisable-N), total copper, zinc, cadmium and nickel. All variables with the exception of soil invertebrates are measured in the top 15cm of the soil profile only. Soil invertebrates are recorded for the top 8cm of soil. This focus on the top 15cm of soil mirrors the focus of several other soil monitoring programmes (e.g. NSI) as it is thought the top soil horizons are thought to be the most susceptible to change over time as they are more immediately affected by land management activities and environmental change. Ideally future soil monitoring should include lower soil horizons as they are important for storage of carbon, supply of nutrients, filtering and storage of contaminants, and as a habitat for soil biota. This is particularly important for carbon storage in peat soils where significant carbon in stored below 15cm.

1.2 Soil sampling and preparation for analysis

As part of the 1978 survey, soil samples from the top approximately 0-15cm were collected from a soil pit in the centre of each of the five Main 'X' Plots (200m^2) randomly located in each of the 256 1km x 1km squares. Maps were drawn to help future relocation. In 1990, permanent metal markers were placed immediately adjacent to the south corner of all plots, as mapped in 1978 (or according to an alternative detailed protocol if within-field placement was inappropriate) during a CS survey which did not involve soil sampling. Samples were taken 15cm to the north of the inner 2m x 2m plot in the centre of the Main Plots in 1998 and to the south in 2007. In 1998 and 2007, maps and markers were requested from the surveyors for all new or changed locations. Samples from 1998 and 2007 were therefore resampled 2-3m apart between each survey. This compares to 20-50m for the National Soil Inventory. In total, the 1978 survey collected 1197 soil samples for analysis. During 1998, surveyors collected soil samples from all plots used for soil sampling in the original 1978 squares and 1098 samples were returned for analysis. (Note a total of 569 squares were visited across GB in 1998 but soil sampling was only included in the original 256 squares.) In 2007, 591 1 km squares were sampled with a total of ca. 11000 samples returned for analysis (591 squares x 5 Main Plots x 4 core types (***Table 1.2***) of which 2614 (591 squares x 5 Main plots – missing cores) were used for bulk density analyses. Some samples could not be taken for practical reasons or were not suitable for analysis.

Table 1.2: Description of CS soil cores.

Core No.	Colour and length	Core measurements	Comments
1	Black 15cm	pH, LOI, Bulk density, %N, Olsen P, metals	Insufficient sample for all analyses if soil was peaty. Core 4 was used in that situation.
2	White 8cm	Invertebrate diversity	
3	White 15cm	Microbial diversity / Persistent organic pollutants (POPs)	Frozen on arrival. Microbial diversity analyses are part of a NERC funded project and are not reported as part of CS. POP analysis was not funded but sampled preserved in case funding becomes available.
4	White 15cm	Mineralisable-N	Samples also used for metals and Olsen P if insufficient sample in Core 1.

The soil (0-15cm) samples enable changes in several key topsoil characteristics to be studied, including pH, soil carbon and nitrogen concentrations and content, a measure of available phosphorus, heavy metal concentrations and soil biota. In addition, measurements of potentially mineralisable nitrogen and bulk density were made for the first time. Three soil samples only were collected from each Main Plot from the top 15cm of the soil profile and a fourth, for the invertebrate sample from the top 8cm only. In 1998 and 2007 this was carried out using a plastic corer hammered into the soil and then pulled out with the sample intact. The plastic was grey or black ABS (acrylonitrile butadiene styrene) water pipe. In 1978, a soil pit was dug and soil was collected from the top 15 cm of the profile in the side of the pit. In all three years, loose vegetation and fresh litter were cleared from the soil surface before the sample was taken. Samples were stored in cold boxes and posted back to the laboratory for analysis. On arrival at the laboratory, all soil cores were logged in, the core extruded from the plastic tube, a digital photograph taken and basic core dimensions taken before processing began. For full information on methodology and Standard Operating Procedures for all variables see the CS Soils Manual (Emmett *et al.* 2008 available at http://www.countrysidesurvey.org.uk/tech_reports.html).

1.3 Bulk density

Soil bulk density (BD) is the single most useful parameter of soil physical structure. It is a direct measure of soil compaction (or loosening) and is essential to assess total available pore space within a soil (that is, total porosity). Soil pore space occupies roughly half of the soils volume, and is essential for the sustainable use of soils since the pores hold air, water and soil biodiversity. Bulk density is an excellent measure of a most important contemporary form of soil degradation: that which occurs due to ill-timed cultivation, compaction by vehicles and stocking, and also affects soil biodiversity since increased BD means reduced macropore volume which is associated with decreases in microbial biomass and activity. The rationale for measurement is outlined in ***Table 1.3*.**

The BD of a soil is also essential in the estimation of soil carbon (C) densities, where it is necessary to convert from % soil organic carbon (SOC) to SOC per unit volume (e.g. g cm^{-3}). Soil carbon stocks (0-15cm) can then be calculated by combining carbon densities with area of Broad Habitat. Changes to soil C density and stocks represent a major component of UK greenhouse gas emissions and under the Kyoto Protocol the UK is required to make estimates of net carbon emissions to the atmosphere. Changes in soil C stock will need to be included in inventories and reporting if these estimates are to be meaningful. To date, our knowledge of soil C stocks and changes is limited; recent work by National Soil Resources Institute (Bellamy *et al.,* 2005) indicates that large changes have occurred recently, but these changes can only be related to broad habitat types. Determinations of soil BD in CS in 2007 will allow the calculation of topsoil C stocks and change from 1998, whilst relating these observed changes to potential pressures and drivers such as land use change, climate change and atmospheric deposition.

We assessed the different methods of extracting soil from the ground for BD determination, including coring and digging a soil pit. Five different cores were tested: 10 cm long x 5 cm diameter round core, 15 cm x 6.4 cm round core, 10 cm long x 5 cm square metal core, 10 cm long x 8 cm square metal core, 8 cm long x 4 cm diameter round core. The soil pit method involved digging a pit, then filling the resulting hole with a plastic bag and using water to measure the volume.

Five field sites were visited, to allow the comparison of 5 different soil types. Soils tested were: clayey soil, sandy soil, peaty soil, stony soil and a woodland loam. Three replicates per extraction method (both coring and pit extraction), per soil type, were taken (excepting sand and clayey sand, as it was decided that the soils were uniform enough for just one sample to be taken). In the laboratory, samples were weighed, separated out onto a tray and dried at 105℃. Once dry, the soils were sieved and stones and soil separated. All components were weighed and the BD calculated excluding stones and other debris.

Table 1.3: Bulk density: rationale for measurement.

	Facts	Comments
History in CS	None	
Links and compatibility to other monitoring programmes	*National Soil Inventory - England & Wales (NSI E&W)* Bulk density estimated from original survey measurements. *National Soil Inventory (NSI Scotland) - Scotland* Some bulk density values available.	Obvious links to NSI E&W and NSI Scotland, particularly in the 2007 Scottish resurvey, which will happen at the same time as CS in 2007. However, BD estimation methods differ and will need to be compared with caution.
	Environmental Change Network Sample soils at 12 terrestrial sites every 5- and 20- years. Bulk density measured every 20 years to depth of 120cm or bedrock.	Only one 20-year sampling has been made – next due in 2013. High intensity measurements on limited number of sites will complement CS data.
Uniqueness of CS	No national dataset to estimate bulk density on every soil sample measured for %C.	
Value for money (Policy priority or interpretative value X cost)	High	High policy and interpretative value, low cost. Cheap, reliable way of assessing soil physical structure. Pedotransfer functions highly relevant for other survey and monitoring programmes.

Overall, the different core types tested gave fairly consistent BD values across soil types and no one core type gave consistently higher/lower BD values (Emmett *et al.* 2008). The values of BD estimated from cores and pits were similar, and were within the ranges of typical values expected for each of the soil types. However, any methods used for sampling in CS must take into account the time available in the field, the capacity of the field team to carry equipment, and the logistics of the survey. The recommendations for BD measurements in CS were as follows:

- **The pit extraction method is not feasible due to the amount of heavy equipment needed and the complexity of the task.**
- **Although the metal square cores tended to hammer in more easily, they tended to distort easily in difficult soils, making their use limited. In 'sticky' soils, some of the sample was left in the corners of the core. They are also heavier to transport by post.**
- **Taking the above into account, the coring method is the only method which can be realistically carried out in a consistent manner on such a large scale.**
- **The black 15 cm cores used in the 1998 are acceptable to use for measuring bulk density in the majority of soils, on the condition that surveyors/lab. personnel follow careful instructions provided in the CS Field Handbook.**

Thus in 2007 CS soils were sampled using the 15 cm long x 5 cm diameter core, hammered into the ground, and removed using pliers as in the 1998 soil survey.

Bulk density was estimated for each soil sample by making detailed weight measurements throughout the soil processing procedure. Briefly, the exact dimensions of the sampled soil core were recorded before the soil was extruded from the plastic tube, and the soil was then weighed, homogenised, reweighed before drying at room temperature for up to two weeks. At the end of this period, the soil was again weighed and then sieved to 2 mm, and the weight and volume of the debris remaining (largely composed of stones and plant material and called unsieved debris) recorded. A sub-sample of 10 g of soil was then accurately weighed and dried overnight at 105 ℃, before LOI determination. The moisture loss at each stage of the process was used to estimate the initial moisture content of the soil, and from that the initial dry weight of the soil. Bulk density was then estimated using the equation:

$$\text{Bulk density (g cm}^{-3}\text{)} = \frac{\text{(dry weight of soil - weight of unsieved debris)}}{\text{(volume of core collected - volume of unsieved debris)}}$$

Data were analysed using the standard mixed model analysis appropriate to CS measurements. The statistical approach used for analysis for change involved bootstrapping which allows for non-normality in the data without the necessity of knowing details of actual distribution. As such it provides a more accurate measurement of significance. Annex F of Emmett *et al.* (2008) provides a background document describing this approach.

1.4 Results

Results are presented for three major categories: Broad Habitats, Aggregate Vegetation Class and Loss on Ignition Category.

- Broad Habitat - The Broad Habitat classification consists of 27 habitats which account for the entire land surface of Great Britain, and the surrounding sea. Countryside Survey reports on 10 major terrestrial habitats.
- Aggregate Vegetation Class (AVC) – is a high level grouping of vegetation types produced from a quantitative hierarchical classification of the different plant species found in the original Countryside Survey sample plots.

- Loss on ignition (LOI) category – soil type based on soil organic matter content defined as mineral (0-8% LOI; 0-44 g C kg^{-1}), humus-mineral (8 – 30% LOI ; 44-165 g C kg^{-1}), organo-mineral (30 – 60% LOI; 165-330 g C kg^{-1}) and organic (60 – 100%; > 330 g C kg^{-1}).

Topsoil bulk density in individual samples in 2007 ranged from 0.02 to 1.95 g cm^{-3}, and was negatively correlated with soil C concentration, with mineral soils exhibiting the highest bulk density values and organic soils the lowest. Average topsoil bulk density across AVC and BH classes varied between 0.2 and 1.2 g cm^{-3} and was lowest in bog soils and highest in arable and horticultural soils (***Table 1.4***). However, within each AVC or BH large ranges of BD values were observed.

There was a strong relationship between C concentration and soil BD in the 2007 data (***Fig. 1.1***) which is significantly different to the commonly used pedotransfer function from Howard *et al.* (1995) and used by Bellamy *et al.* (2005). This relationship can be applied to the 1978 and 1998 LOI data to estimate BD in those years. This is required if estimates of soil density of C or other element are required between surveys. To limit the accumulation of errors through applying successive empirical transformations to the data, the 2007 relationship between C concentration and density (calculated directly from the 2007 data) was used to estimate C density from concentration in 1978 and 1998 in ***Section 2.3 and 2.4***. Since the relationship between C concentration and bulk density is non-linear, average C densities cannot be calculated directly from average concentration and bulk density values; i.e. multiplying the values in %C in Section 2; ***Tables 2.4, 2.6, 2.8*, *2.10*** will not produce the C density estimates in ***Tables 2.5, 2.7, 2.9, 2.11 and 2.12*.**

CS estimates of topsoil C density assume that the relationship between C concentration and BD in 2007 is the same in 1978 and 1998. Since there are no studies of changes in BD over time across the entire range of C concentrations, this assumption remains untested. A range of factors such as land-use specific effects and soil moisture variation are likely to contribute to the large variation in BD at any given C concentration (***Fig. 1.1***), but given the large sample size and representative nature of CS data it is unlikely that the overall C concentration-BD relationship will change significantly over time.

Table 1.4 Bulk density (g cm^{-3}) in different Broad Habitat Classes, Aggregate Vegetation Classes and Loss on ignition (%) categories.

a) Great Britain - Broad Habitat

Broad Habitat	2007
Broadleaved, Mixed and Yew Woodland	0.78
Coniferous Woodland	0.52
Arable and Horticulture	1.23
Improved Grassland	0.97
Neutral Grassland	0.90
Acid Grassland	0.43
Bracken	0.43
Dwarf Shrub Heath	0.35
Fen, Marsh and Swamp	0.45
Bog	0.17
All habitat types	0.78

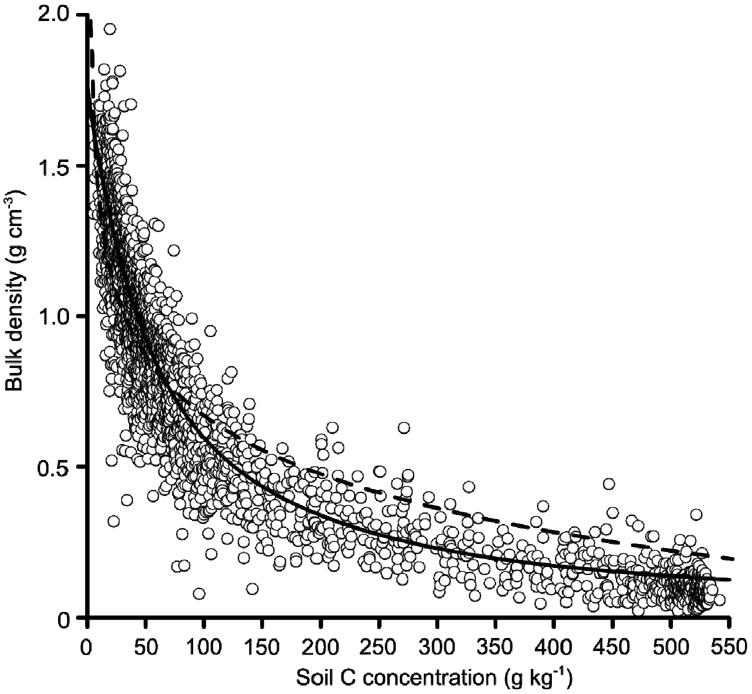
b) AVC - whole dataset

Aggregate Vegetation Class	2007
Upland Woodland	0.53
Lowland Woodland	0.82
Fertile Grassland	1.03
Infertile Grassland	0.88
Moorland Grass Mosaics	0.41
Heath and Bog	0.21
Tall Grass and Herb	1.05
Crops and Weeds	1.25

c) Loss on ignition category

LOI category (%)	2007
Mineral (0-8)	1.17
Humus-mineral (8-30)	0.77
Organo-mineral (30-60)	0.36
Organic (60-100)	0.14

Figure 1.1 Relationship between topsoil C concentration and bulk density in CS in 2007. Circles are estimates from Countryside Survey samples in 2007, the solid line is the regression line of the data ($y = 1.29e^{-0.0206x} + 2.51e^{-0.0003x} - 2.057$), the dashed line is the estimate of bulk density derived from a commonly-used pedotransfer function ($y = 1.3 - 0.275\ln(x/10)$; Howard *et al.*,1995, as used in Bellamy *et al.*, 2005).



1.5 Discussion and Policy Implications

To our knowledge, our measurements of topsoil BD represent the most comprehensive dataset available for GB to date. ***Figure 1.1*** compares our BD results with that of the pedotransfer function first used by Howard *et al*. (1995) and subsequently by Bellamy *et al.* (2005). For C concentrations greater than 68 g C kg^{-1}, the Howard *et al.*, 1995 equation overestimates BD, especially at high C concentrations. Using the Howard *et al.*, 1995 equation, soils containing >400 g C kg^{-1} are constrained to possess a BD of 0.22-0.28 g cm^{-3}, but CS results show that 92% of soils containing >400 g C kg^{-1} exhibit BD <0.2 g cm^{-3}, and 51% have a BD <0.1 g cm^{-3}. Very low BD for highly organic topsoils has been reported by other authors (e.g. Givelet *et al.*, 2004; van der Linden *et al.* (2008). The differences in the two BD equations have implications for the estimates of topsoil C stock and change given by Bellamy *et al.*, 2005. Our estimate of 949 Tg for the total topsoil C stock of England and Wales in 1978 is substantially larger than the 864 Tg estimated by Bellamy *et al*. (2005), however this is partly due to different conversion factors used; assuming that C is 50% of LOI (as Bellamy *et al*., 2005) rather than 55% (the value used here), CS data yields an estimate of 863 Tg C for England and Wales in 1978. However, the different BD equations produce estimates of C stock at specific C concentrations that vary considerably; Bellamy *et al.* (2005) estimated that soils in England and Wales which contained >300 g C kg^{-1} in 1978 had a total topsoil (0-15 cm) C stock of 122 Tg. Using the more realistic CS equation to estimate topsoil C stock for these soils reduced this value to ca. 73 Tg, and on the same basis would reduce the estimated loss of C from these soils from 2.1 to ca. 1.2 Tg yr^{-1}. However, these revised estimates of topsoil C stocks do not explain the substantial differences between our results and those of Bellamy *et al.*, 2005 in terms of change in topsoil C concentration and stock. Reasons for this continue to be explored. The importance of the modified transfer function is less important when bulk density is used as an indicator of soil quality associated with land management practices as change rather than absolute value in these situations is usually of greater interest.

1.6 References

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Summary

- **Carbon concentration in the soil (0-15 cm) increased in Great Britain between 1978 and 1998, and decreased between 1998 and 2007. Overall there was no change in carbon concentration in the soil (0-15 cm) in Great Britain between 1978 and 2007 and cannot confirm the loss reported by the National Soil Inventory**

- **The one consistent exception is loss of carbon (0-15cm) from the intensively managed Arable and Horticulture Broad Habitat / Crops and Weeds Aggregate Vegetation Class. This suggests that current policies in place to limit soil degradation are not maintaining soil quality in cropped land.**

- **The mean soil (0-15cm) carbon density across Great Britain in 2007 was calculated to be 69 t/ha, ranging between a mean of 47 t/ha in the Arable Broad Habitat to a mean of 91 t/ha in Acid Grassland. Peat soils do not contain the highest density in topsoil due to low bulk densities. A new transfer function between bulk density and %C has been defined which significantly changes past estimates of soil carbon densities, stocks and change (0-15cm) of organic soils previously published for other surveys.**

- **Area estimates for each Broad Habitat were used to convert soil carbon densities to soil (0-15cm) carbon stock for GB and individual countries. Soil (0-15cm) values were 1582 TgC for GB and 795TgC, 628 TgC and 159 TgC for England, Scotland and Wales in 2007 respectively. It must be emphasised this significantly underestimates the total carbon stock in soils due to the large carbon stores at depth particularly in peat soils. This has greatest impact for estimates for Scotland. However, topsoil carbon stocks may be most vulnerable to land management activities and environmental change.**

2.1 Policy Background[1]

Key question: Can we confirm the loss of soil carbon (0-15cm) as reported by Bellamy et al., 2005?

Measurements: Organic matter content by loss-on-ignition of soil (0-15cm) in repeats of all plots sampled in 1978 and 1998 and all additional plots sampled in 2007. Carbon concentration data of soil (0-15cm) in repeats of all plots sampled in 1998 and repeated in 2007. By combining these data and linking to bulk density measurements, CS in 2007 has delivered:

- **Whole GB and country-level assessment of status and change of soil (0-15cm) carbon concentration, density and stock between 1978, 1998 and 2007**

2. Carbon

Soil organic C (SOC) is one of the headline indictors of soil quality and there is a wide acceptance that carbon is fundamental to soil functioning as it is the primary energy source in soils and has a critical role in maintaining soil structural condition and resilience and water retention. All soils therefore need to retain carbon. However, soil C changes are measured against large background stocks and high spatial heterogeneity, and more information is needed to be able to manage this resource better. Specific policy requirements which require improved information on the status and change of soil carbon content include UK and EU legislation soil protection measures that will help to conserve soil carbon. The reformed Common Agriculture Policy requires all farmers in receipt of the single payment to take measures to protect their soil from erosion, organic matter decline and structural damage. Changes to soil C content also represent a major component of UK greenhouse gas emissions and under the Kyoto Protocol the UK is required to make estimates of net carbon emissions to the atmosphere. However, knowledge of soil C stocks and changes is limited; recent work by the NSRI (Bellamy *et al*., 2005) indicates that large changes have occurred recently, but there has been some debate concerning possible causes (Smith *et al.* 2007). In addition, if stocks could be related to more detailed vegetation and other environmental data this would allow better mitigation targeting. Whereas above ground carbon cycling is well understood, there are great uncertainties in climate impacts on soil carbon cycling. CS soil C data will contribute to knowledge of how soil C is changing, how this relates to vegetation change and land use and management and provide evidence of the effectiveness of soil protection legislation.

Soil samples taken for Countryside Survey in 2007 will be the third in a time series of samples from 1978 and 1998; this will be the first national soil time-series in Europe and possibly globally. Analyses of topsoil C in 2007 will allow further quantification of topsoil C contents and change across all major UK land uses and, crucially, through the link to other CS and spatially relevant information, will allow the assignment of pressures and drivers to the observed changes, be they climate change, land use and management or atmospheric deposition. This link to drivers of change will be reported in the CS Integrated Assessment Report and peer-reviewed literature.

2.2 Methods

2.2.1 Proof of concept

Loss-on-ignition (LOI) is a simple and inexpensive method for determining soil organic matter and estimating soil organic carbon concentration (hereafter called soil C concentration) using an appropriate conversion equation. An analysis of the benefits of including the measurement in the 2007 survey is summarised in ***Table 2.1***.

LOI values were determined for 1197 plots within 256 1km squares in 1978, 1098 plots within 256 squares in 1998 and 2614 plots within 591 squares in 2007. The increase in sample number was necessary to provide adequate statistical power to detect change within all three GB countries. Power analysis of the existing CS dataset (1978 & 1998) was performed to determine the number of squares needed in 2007 to give adequate reporting power for soils in Wales, and greater power for soils in Scotland and England. For further information see Emmett *et al.* (2008). Essentially sampling within CS can determine significant differences in soil C concentration if these are greater than 8% of previous estimates.

In 1978 and 1998 LOI was performed on 10 g soil at 375°C for 16 hours and on 1 g soil at 550°C for 3 hours, respectively. In the preparation phase for CS in 2007 it was identified that the 1998 LOI method had resulted in higher values of LOI across the entire soil organic matter range relative to the 1978 method, and it was decided that all available 1998 soils would be reanalysed using the 1978 method. Additionally, it was decided to use the 1978 LOI method in 2007, as 1) this would yield a consistent dataset across 1978, 1998 and 2007, and 2) the use of 10 g soil for LOI is preferable since it is more representative than 1 g.

Alongside LOI measurements, soil C concentration was determined by elemental analyser analysis in 1998 and again in 2007. This measurement complements the LOI data since it is an actual measurement of C concentration in soil, however in soils with high amounts of carbonates the soil C concentration may be considerably larger than the organic C concentration. Soil C concentration cannot replace LOI as a method of measuring soil C because 1978 samples were only analysed by LOI and not by soil C concentration.

A conversion factor of 0.5 from the literature has been used to convert LOI to soil C concentration for CS reports to date. The completed analysis of the combined analysis of 1998 and 2007 data for LOI has indicated a different value of 0.55 which is now being used in all estimates of soil C concentration and carbon density.

To calculate topsoil carbon density on a g cm^{-3} basis, a measurement of C per unit volume is needed. Combining bulk density measurements reported in Chapter 1 for the 2007 samples with LOI/soil C concentration values result in estimates of topsoil C density on an area basis. This in turn can be combined with Broad Habitat area estimates from the CS surveys leading to the first national survey assessment of topsoil carbon stock (0-15cm) derived from co-located measured variables.

Table 2.1: LOI, soil C concentration, density and stock: Rationale for measurement

Issue	Facts	Comments
History in CS		
Loss-on-ignition	Measured in 1978 and 1998 for 256 squares. Expanded to 591 squares in 2007.	Repeat sampling will maintain the time series. The increased spatial coverage will support country-level reporting by giving greater statistical power, especially for Wales (see below).
Topsoil total C content (%)	Gives total soil C content measured by elemental analyser in 1998 and 2007 on original plots which can be used to convert all 2007 LOI values.	Data obtained from same analytical run as that of total soil N content.
Topsoil carbon density (g cm^{-3})	A conversion function will be obtained from 2007 bulk density values.	This function will allow change in soil carbon density to be determined for all time periods.
Links and compatibility to other monitoring programmes	National Soil Inventory- England & Wales. Information from 5500 locations in England & Wales including C and soil horizon information.	Data comparability exercise for Defra (Project SP0515).
	National Soil Inventory - Scotland Data from 770 locations includes %C and soil horizon information. A partial repeat survey in Scotland was carried out 2007 – 2009.	Analysis of repeat survey results in progress.
	Environmental Change Network Soil monitoring at 12 terrestrial sites every 5 & 20 years. Total organic C and bulk density in both 5 and 20-year determinands. Dissolved organic C	ECN data not available.

	measured in soils every 2 weeks.	
	Representative Soil Sampling Scheme (RSSS). Carried out since 1969 - 2003, soil samples taken from stratified random sample of 180 farms. Runs on a five-year sampling cycle, with a subset of the selected farms sampled each year.	RSSS not measured SOC since 1984.
	UK Woodland resurvey.	Data available for 103 woodlands.
	Biosoil and Level II plots.	Data in preparation.
Uniqueness of CS		
LOI and %C (0-15cm)	CS soil samples are spatially linked to many other data collected at the same time. It is unique in that the results can be linked to pressures and drivers, e.g. vegetation, deposition, land management.	Sampling of soil in close proximity to the detailed vegetations characterisations is vital in the investigation of relationships between land use/habitat and soil characteristics.
Carbon density and stock (0-15cm)	CS measures the bulk density of each soil sample, which when combined with area enables anb estimate of soil (0-15cm) C stock.	Topsoil bulk density (BD) has not been measured within any large-scale soil survey until now. The data can be used to determine how stable BD is over time and whether BD measured or estimated are required to assess soil carbon changes.
Value for money (Policy priority or interpretative value x cost)		
LOI and soil C concentration (g kg^{-1})	High	High policy and interpretative value (time series), low cost. Expansion to all CS squares future-proofs data for further Surveys.
Topsoil C stock	High	High policy and interpretative value, low cost.

2.2.2 Laboratory analysis

Samples for LOI were collected using the 15cm long by 5cm diameter black plastic core following the field protocol described in Chapter 1 and in more detail in Emmett *et al.* (2008). LOI was measured on a 10 g air dried sub-sample taken after sieving to 2 mm. The sub-sample was dried at 105℃ for 16 hours to remove moisture, weighed, then combusted at 375℃ for 16 hours. The cooled sample was then weighed, and the loss-on-ignition (%) calculated. Soil C concentration was determined, using a total elemental analyser for the original 256 squares. The method used was CEH Lancaster UKAS accredited method SOP3102. Details of the method are given in Emmett *et al.* (2008).

2.2.3 Quality Assurance and Quality Control

The Defra/NERC Joint Codes of Practice were followed throughout.

Method comparability: A selection of 40 soils from 1998 were analysed by LOI using the methodologies used in the 1978 and 1998 surveys (***Table 2.2***). Results gave good agreement over the whole range of LOI values (***Fig. 2.1***) but across the whole dataset mean LOI values were significantly lower (-1.2%) using the 1978 method compared to the 1998 method (***Table 2.3***). This difference in the results using the 1978 method was present regardless of whether the soils were heated for 2¼ or 3 hr (mean decrease -1.14 and -1.43 %, respectively.

Table 2.2: LOI method conditions in 1978 and original 1998 method.

Survey	Amount of soil (g)	Temp (℃)	Time (hr)
1978	10	375	16
1998	1	550	Not less than 2

Figure 2.1: Comparison of LOI using 1978 and original 1998 method.

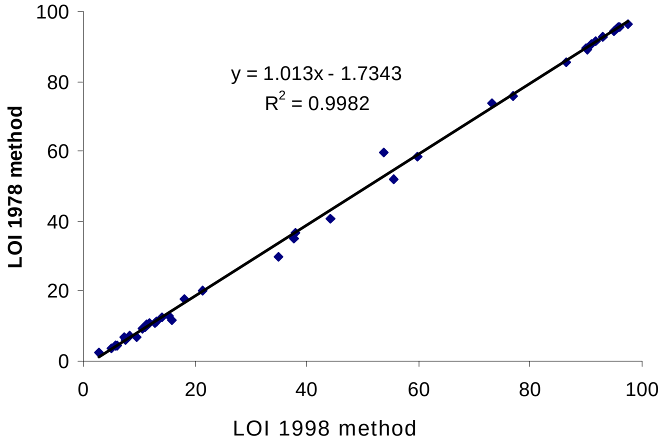


Table 2.3: Differences in LOI results, as a deviation from 1978 results, using 1978 and original 1998 methods.

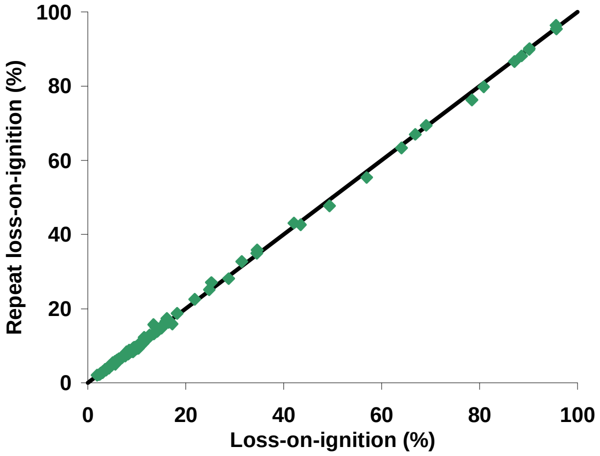
LOI	Mean difference 1978-1998	SD	SE
<20%	-1.5	0.8	0.2
20-80%	-1.2	3.2	1.1
>80%	-0.6	0.3	0.1

The results also show that the observed differences in LOI results are more pronounced at lower organic matter contents, where the 1978 method gave LOI values approx. 1.5% lower than the 1998 method at LOI values < 20%, compared with 0.6% lower at LOI values >80% (***Table 2.3***). These lower LOI values produced by the 1978 method are much more important when the organic matter content is low, as a small change in total organic matter content is a large relative change in organic matter.

These differences were not considered acceptable and all 1998 samples with sufficient sample remaining were re-analysed using the 1978 method. A transformation was devised for the remaining samples using the relationship derived from those where dual analyses were available. All samples in 2007 were analysed using the 1978 methodology.

Analytical QC: In each analytical batch of samples for LOI in 2007, one soil was repeated. The comparison between the two replicates indicates clear reproducibility of results (***Fig. 2.2***)

Figure 2.2: Reproducibility of LOI measurements on repeated samples in 2007.



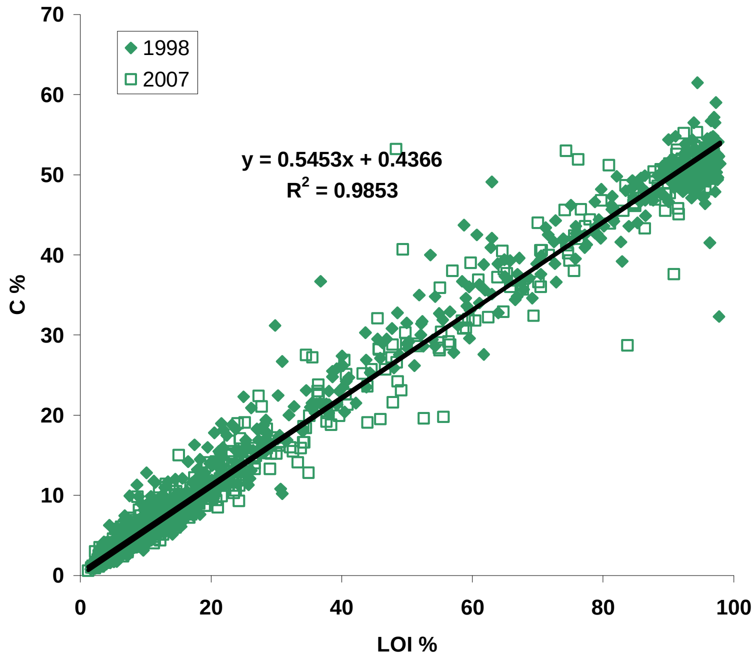
Conversion to soil C concentration: For the main CS report released in November 2008, the soil loss-on-ignition (LOI) to soil C concentration (g kg^{-1}) relationship was considered to be:

soil C concentration = 0.5LOI

This value was derived from the literature and was used because at that time only soil C concentration data for 1998 were available and it was not known if the new LOI to soil C concentration relationship was stable and reproducible between years. The soil C concentration data for 2007 are now available, and have been compared with that from 1998. ***Fig. 2.3*** demonstrates that, to two decimal places, the regression relationship between LOI and soil C concentration was the same in both 1998 and 2007:

soil C concentration = 0.55LOI

Figure 2.3: The relationship between %LOI and soil C concentration (%) for 1998 and 2007 soils.



It should be noted that whilst these relationships have been shown for 1998 and 2007 we have no measurements for 1978. It cannot therefore be demonstrated that such a relationship would hold in that year. However, there seems no scientific reason to consider that the relationship would not hold in 1978.

Since there is now a CS-specific LOI-soil C concentration relationship, better estimates of topsoil C concentration and density will be produced if the CS relationship is used, compared to the literature derived value. However, the estimates reported in the main CS report will then differ from those in the CS soils report. The difference is simple: since the proportion of LOI accounted for by C has increased by 10% (from 0.5 to 0.55), all previous estimates of C concentration and density will also increase by 10%.

2.2.4 Reporting

The Broad Habitat (BH) classification has been developed over the last 15 years and currently consists of 27 habitats which account for the entire land surface of Great Britain, and the surrounding sea (Jackson, 2000). The BH areas in CS have a minimum mappable unit size of 400 m^2 (Carey *et al.*, 2008). Since some Broad Habitats contain no soil, and others are rare and so not encountered frequently in CS, only 10 BH are reported here. Additionally, due to the lack of mapped habitat information in 1978, all reporting by BH refers to the 2007 habitat allocation for the parcel in which each vegetation plot resides, except when the plot was not sampled in 2007 in which case the 1998 BH allocation was used. In summary, the BH is a description of a parcel of land (e.g. an arable field), whilst the AVC is a description of a plot within a parcel (e.g. a small patch of lowland woodland at the edge of an arable field); the AVC may not therefore be representative of the whole parcel, and may differ from the BH, but is representative of the vegetation above the soil sampling locations. BH areas in 2007 were taken from Carey *et al.* (2008). A soil type category has also been developed based on soil organic matter content. In summary:

- Broad Habitat - The Broad Habitat classification consists of 27 habitats which account for the entire land surface of Great Britain, and the surrounding sea. Countryside Survey reports on soils for 10 major terrestrial habitats.
- Aggregate Vegetation Class (AVC) – is a high level grouping of vegetation types produced from a quantitative hierarchical classification of the different plant species found in the original Countryside Survey sample plots.
- Loss on ignition (LOI) category – soil type based on soil organic matter content defined as mineral (0-8% LOI; 0-44 g C kg^{-1}), humus-mineral (8 – 30% LOI ; 44-165 g C kg^{-1}), organo-mineral (30 – 60% LOI; 165-330 g C kg^{-1}) and organic (60 – 100%; > 330 g C kg^{-1}).

The soil C concentration values were mapped using kriging to interpolate between the Countryside Survey sample points. Routine checking of data for outliers was conducted and the working data set was transformed using a normal score procedure to obtain a Gaussian distribution. The data were then interpolated on a 1km UK grid using ordinary kriging and finally, the kriged data were back-transformed to produce an interpolated map of soil C concentration. In addition, Sequential Gaussian simulation (SGs) was conducted on the data to obtain the E-type estimate (mean) and the spatial uncertainty for the data (conditional variance). Both the coefficient of variation, CV, (standard deviation / mean) and the signal to noise ratio, SNR, (mean / standard deviation) are reported.

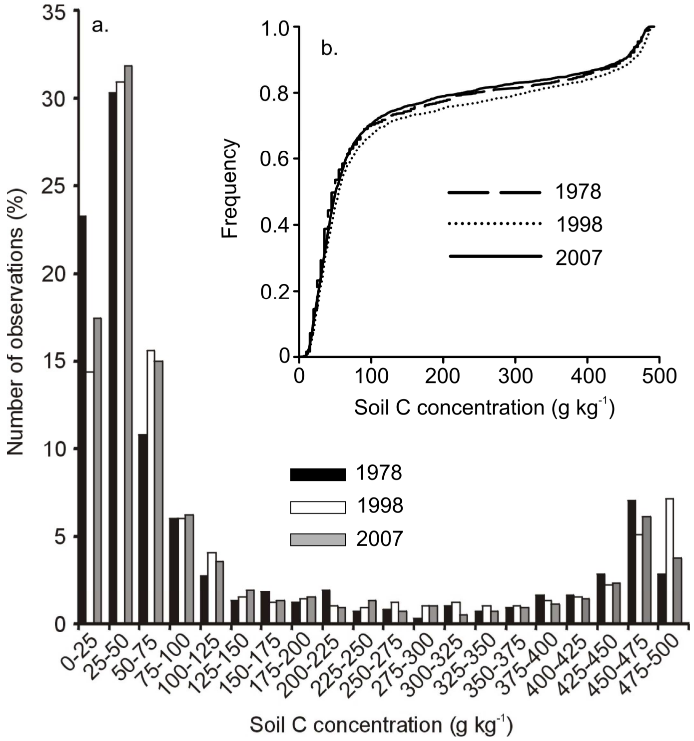
2.3 Results

2.3.1 Structure of soil (0-15cm) LOI data and conversion to soil C concentration

Recorded LOI values were in the range 1.0 – 98.5%, corresponding to topsoil C concentrations of 5.5 – 541.8 g C kg^{-1}.). The maximum C concentration possible in a soil is 550 g kg^{-1} using the conversion factor 0.55. The distribution of C concentrations across the observed range is shown in ***Fig. 2.4***. The mix of soils across GB has a characteristic bi-modal U-shaped distribution pattern, with the majority of soils containing <100 g C kg^{-1}. Across the three Surveys mineral, humus-mineral, organo-mineral, and organic topsoils accounted for 34-39, 35-38, 6-7 and 17-21% of all samples, respectively.

Within CS, 58% of samples (2843 samples) come from plots which have been sampled more than once. Therefore, 42% of samples come from plots only sampled once, primarily due to the many extra sampling locations in 2007. Some variation in C concentration in repeat plots would be expected due to occasional failure in relocating the exact plot, soil heterogeneity, differences in sampling procedures across the Surveys, and real change over time. However, the vast majority of observed differences in repeat plots were small (***Fig. 2.4***); 83-91% of differences in repeat plots were <100 g C kg^{-1} (<20% LOI). At the other end of the scale, 1-5% of all differences from repeat plots were >300 g kg^{-1} (>60% LOI). Such large differences are highly unlikely to be due to real change in soil C concentration, and suggest that soils in some locations were extremely heterogeneous, or that surveyors were not always successful in accurately re-locating plots.

Figure 2.4: Distribution of Countryside Survey soil C concentration data (0-15cm) (a) Number of observations for 25 g kg^{-1} divisions, (b) Cumulative frequency.

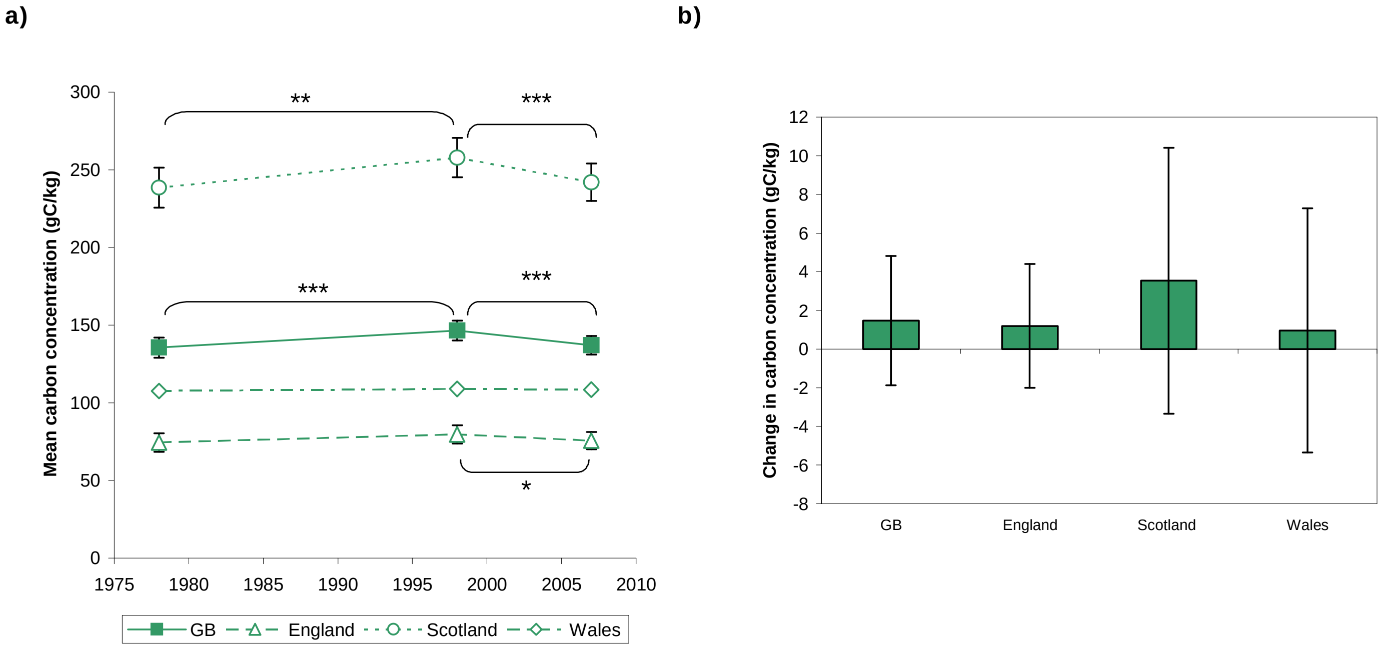


2.3.2 Change in soil (0-15cm) C concentration and density across Great Britain

At the highest level of analysis for GB as a whole and for the whole 29 year period between 1978 and 2007 no net significant change in soil C concentration (0-15cm) was observed (***Fig. 2.5a & b***). Trends over time were significant for Scotland and GB only with both showing a significant increase between 1978 and 1998 followed by a significant decline between 1998 and 2007 with no overall change over the whole 29 year period. The 1998 Survey contained a greater frequency of soils with higher LOI values which led to higher estimates of soil C concentrations that year. We can find no systematic bias in our data (e.g. an undersampling of a particular habitat, soil type or geographical area) which could lead to this distribution and the potential drivers of this temporal pattern is currently being investigated and will be reported in the Integrated Assessment Report. The overall picture is one of little large-scale change in topsoil C concentrations in the long term.

Mean soil C concentrations for individual countries vary due to the different frequencies of soil type. Soil C concentration increases in the order England<Wales<Scotland. No significant change by soil carbon category was observed (***Fig. 2.5b***). Trends for individual countries are discussed more fully in the individual country sections.

Figure 2.5: Change in soil C concentration (0-15cm) for GB and individual countries (a) over time and (b) net change between 1978 and 2007. Standard errors are indicated. Significant differences (* $p<0.001$, * $p<0.01$, * $p<0.05$) are shown between the years bracketed.**



Significant changes were observed within and between the different Broad Habitat, Aggregate Vegetation Classes, soil carbon categories and between the individual survey years (***Table 2.4***).

Amongst BHs, which represent the larger habitat unit within which each soil sampling location resides, topsoil C concentrations in 1978 and 2007 were significantly different in Arable and Horticulture, Bracken, and Broadleaf Woodland soils (***Table 2.4a***). Note that the BH is based on 2007 recording (and occasionally on the 1998 data), since the BH classification did not exist in 1978. There were very low numbers of soil samples in the Bracken BH in 1978 and 1998 – 10 and 12, respectively – so estimates for these years are likely to be inaccurate. The 2007 estimate, which is based on 53 samples, is more likely to represent a reasonable value of the C concentration in the Bracken BH, and the significant change is likely an effect of better representation in 2007

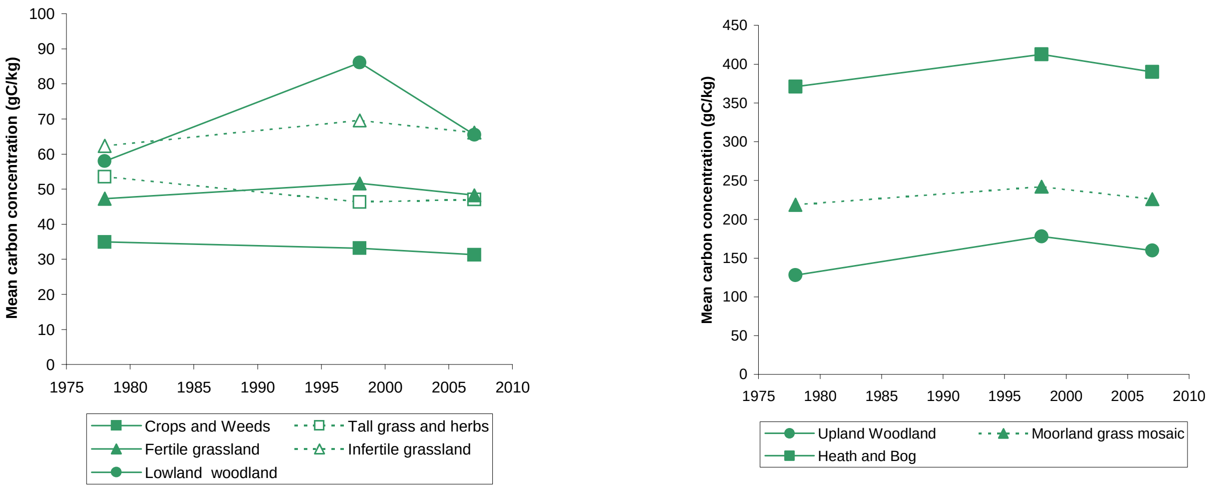
The pattern of higher C concentrations in 1998 compared with the other Survey years also occurred within many Aggregate Vegetation Classes, although changes were not always significant (***Table 2.4b***, ***Fig. 2.6***). Within AVCs, the only significant differences in topsoil C concentration over the whole 29 year period were a decrease in arable soils (AVC Crops and Weeds) and an increase in all woodlands (the combined Lowland and Upland Woodland AVCs) (***Fig. 2.7a***). In 1978, 1998 and 2007, CS sampled 23, 29 and 81 lowland woodlands, respectively, and 76, 71 and 198 Upland Woodlands. Coverage of these AVCs was low in both 1978 and 1998 due to the smaller number of samples taken in these years, and the infrequent occurrence of woodlands in the GB countryside. Larger areas of woodlands and greater numbers of soil samples collected have contributed to greater numbers of woodland soil samples in 2007. Our report of topsoil C concentration change in woodlands should therefore be seen in the context of low sample numbers in 1978 and 1998, and represents our best estimates based on available CS data.

To remove the effects of large-scale vegetation/land use change, we also estimated topsoil C concentrations in plots which were sampled in all three Surveys, and in which the AVC did not change over time (**Table 2.4c**). Since the AVC of the plots is only known for the Survey years we cannot rule out changes in the intervening years e.g. rotation between arable and grassland systems. Therefore plots where the AVC has not changed are plots in which the vegetation composition has been largely consistent in 1978, 1998 and 2007. Only 405 plots had consistent AVCs in the three Surveys, and because of this there were insufficient samples in the Tall Grass and Herb AVC, and soils in this category were ignored. Additionally, the lowland and Upland Woodland AVCs were grouped into one category, all woodlands, due to the small number of samples in each category individually. Nevertheless, trends in these plots were broadly consistent with those observed for the whole dataset suggesting that shifts in AVC (i.e. land use change) are unlikely to be a major factor in determining soil C concentration changes over time.

Within soil C group categories, there were significant increases in soil C concentration between 1978 and 1998 for mineral and organic soils; however subsequent declines in the period 1998 to 2007 led to no significant changes between 1978 and 2007 (***Table 2.4d***, ***Fig. 2.7b***).

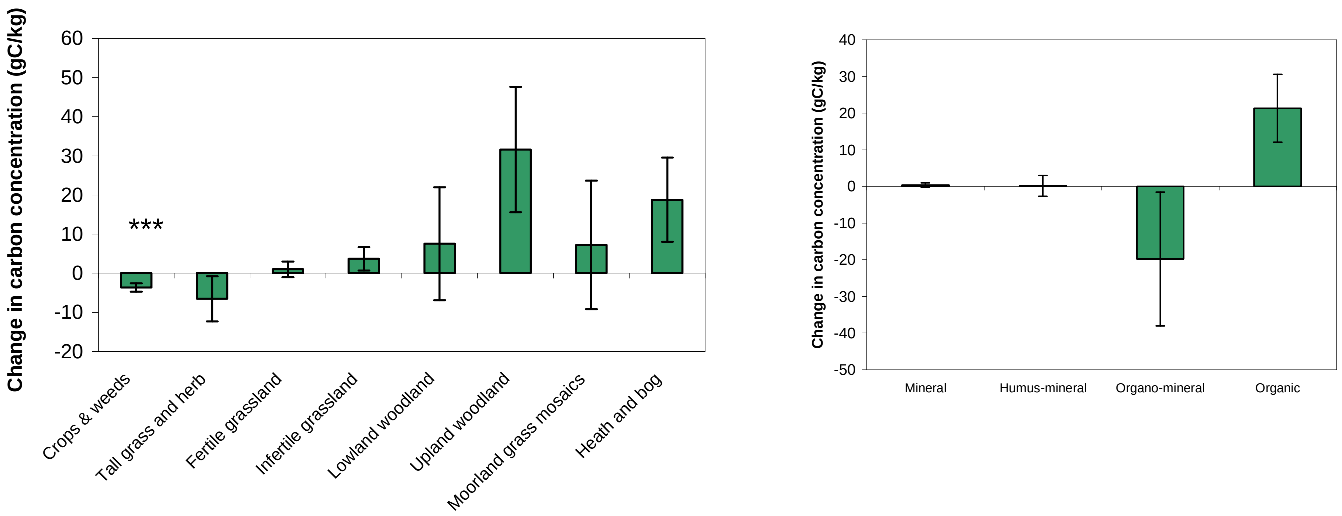
When soil C concentration (0-15cm) was converted to carbon density using the bulk density transfer function, the significant reduction in Broad Habitat Arable and Horticulture and AVC Crops and Weeds categories was again apparent (***Fig. 2.8***, ***Table 2.5***). This appears the most consistent of all trends identified by CS in 2007 whether expressed as C concentration or density.

Figure 2.6: The change in soil C concentrations (0-15cm) between 1978, 1998 and 2007 across AVC classifications characterised by (a) low – medium topsoil C concentrations and (b) high topsoil C concentrations. Significant changes are indicated in Table 2.4.



a) **b)**

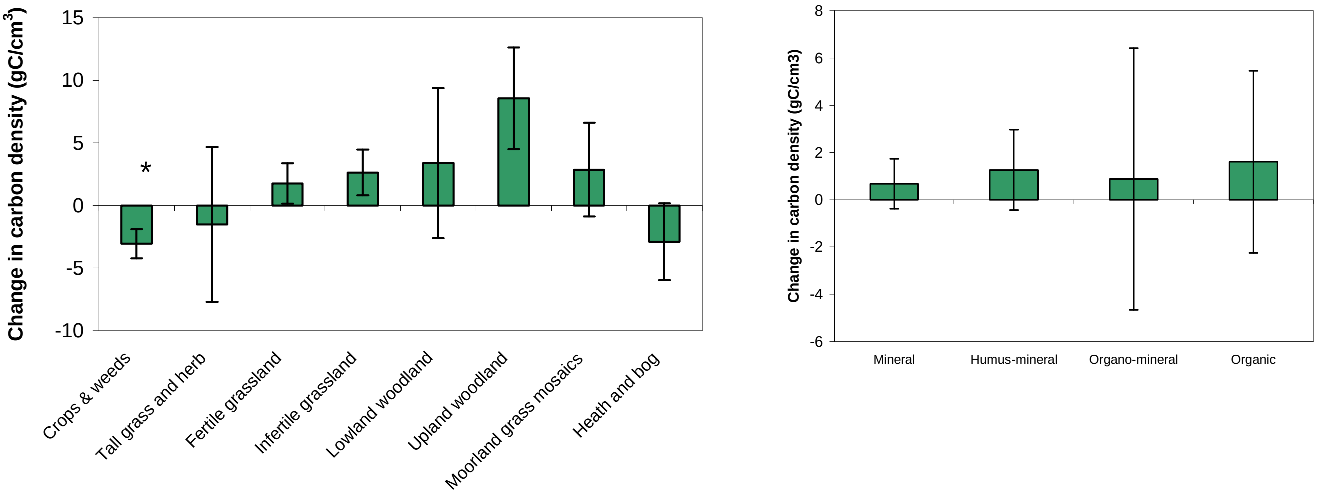
Figure 2.7: Overall change in soil C concentrations (0-15cm) between 1978 and 2007 (a) across AVC categories and (b) LOI categories. Standard errors are indicated. Significant differences (* p<0.001) are shown.**



a)

b)

Figure 2.8: Overall change in soil C density (0-15cm) between 1978 and 2007 (a) across AVC categories and (b) LOI categories. Standard errors are indicated. Significant differences (* p<0.05) are shown.



a)

b)

Table 2.4: Changes in soil C concentration (0-15cm) in GB for (a) Broad Habitats (b) Aggregate Vegetation Class (AVC) (c) AVCs unchanged since 1978 and (d) LOI categories. Arrows denote significant change ($p<0.05$ level) in the direction shown. Diagonal line indicates too few samples to provide reliable value.

a) Great Britain - Broad Habitat

	Mean carbon concentration g/kg^{-1}			Direction of significant changes		
Broad Habitat	1978	1998	2007	1978-1998	1998-2007	1978-2007
Broadleaved, Mixed and Yew Woodland	62.4	102.2	88.7	↑		↑
Coniferous Woodland	203.7	222.0	197.8		↓	
Arable and Horticulture	34.5	33.5	30.7		↓	↓
Improved Grassland	56.4	58.3	56.9			
Neutral Grassland	67.1	70.1	68.0			
Acid Grassland	235.1	256.7	228.5		↓	
Bracken	155.2	154.7	195.9		↑	↑
Dwarf Shrub Heath	305.3	298.7	284.9			
Fen, Marsh and Swamp	231.7	252.8	228.6			
Bog	411.8	449.9	432.9	↑		
All habitat types	135.6	146.5	137.0	↑	↓	

b) AVC - whole dataset

	Mean carbon concentration g/kg^{-1}			Direction of significant changes		
Aggregate Vegetation Class	1978	1998	2007	1978-1998	1998-2007	1978-2007
All Woodlands	103.7	143.0	130.9	↑		↑
Upland Woodland	128.2	178.0	159.8	↑		
Lowland Woodland	58.0	86.1	65.5	↑		
Fertile Grassland	47.3	51.6	48.3	↑	↓	
Infertile Grassland	62.4	69.6	66.1	↑		
Moorland Grass Mosaics	218.6	242.0	225.8			
Heath and Bog	371.0	412.7	389.8	↑		
Tall Grass and Herb	53.6	46.3	47.0			
Crops and Weeds	34.9	33.2	31.3		↓	↓

c) AVC unchanged

	Mean carbon concentration g/kg^{-1}			Direction of significant changes		
Aggregate Vegetation Class	1978	1998	2007	1978-1998	1998-2007	1978-2007
All Woodlands	80.0	139.4	146.5	↑		↑
Upland Woodland	/	/	/	/	/	/
Lowland Woodland	/	/	/	/	/	/
Fertile Grassland	50.9	55.5	54.8			
Infertile Grassland	69.4	73.1	71.1			
Moorland Grass Mosaics	264.6	294.1	264.9			
Heath and Bog	413.7	452.7	436.6	↑		
Tall Grass and Herb	/	/	/	/	/	/
Crops and Weeds	28.9	28.2	25.1		↓	↓

d) Loss on ignition category

	Mean carbon concentration g/kg^{-1}			Direction of significant changes		
LOI category (%)	1978	1998	2007	1978-1998	1998-2007	1978-2007
Mineral (0-8)	29.8	32.7	30.2	↑	↓	
Humus-mineral (8-30)	76.1	78.7	76.2			
Organo-mineral (30-60)	252.1	268.2	232.2		↓	
Organic (60-100)	446.6	482.4	467.9	↑		

Table 2.5: Changes in soil C density (0-15cm) in GB for (a) Broad Habitats (b) Aggregate Vegetation Class (AVC) (c) AVCs unchanged since 1978 and (d) LOI categories. Arrows denote significant change (p<0.05 level) in the direction shown. Diagonal line indicates too few samples to provide reliable value.

a) Great Britain - Broad Habitat

	Mean Carbon Density (t/ha)			Direction of significant changes		
Broad Habitat	1978	1998	2007	1978-1998	1998-2007	1978-2007
Broadleaved, Mixed and Yew Woodland	65.9	76.9	72.9			
Coniferous Woodland	83.7	84.0	81.4			
Arable and Horticulture	53.0	51.8	47.3		↓	↓
Improved Grassland	65.7	67.9	67.2			
Neutral Grassland	65.5	71.7	68.6	↑		
Acid Grassland	91.6	88.9	90.6			
Bracken	74.3	99.2	84.7	↑		
Dwarf Shrub Heath	84.2	83.9	89.9			
Fen, Marsh and Swamp	85.7	82.1	82.8			
Bog	83.4	81.3	85.6			
All habitat types	68.7	70.6	69.3			

b) AVC - whole dataset

	Mean Carbon Density (t/ha)			Direction of significant changes		
Aggregate Vegetation Class	1978	1998	2007	1978-1998	1998-2007	1978-2007
All Woodlands	72.2	79.6	79.6			
Upland Woodland	76.1	83.5	84.7			
Lowland Woodland	64.9	70.7	68.3			
Fertile Grassland	60.8	65.9	62.6	↑	↓	
Infertile Grassland	69.0	73.6	71.6	↑		
Moorland Grass Mosaics	86.9	89.7	89.8			
Heath and Bog	82.4	83.5	84.4			
Tall Grass and Herb	59.6	60.4	58.1			
Crops and Weeds	50.9	51.2	47.9		↓	↓

c) AVC unchanged

	Mean Carbon Density (t/ha)			Direction of significant changes		
Aggregate Vegetation Class	1978	1998	2007	1978-1998	1998-2007	1978-2007
All Woodlands	66.2	90.5	78.4	↑		
Upland Woodland	/	/	/	/	/	/
Lowland Woodland	/	/	/	/	/	/
Fertile Grassland	62.8	69.0	69.9	↑		↑
Infertile Grassland	71.1	73.8	72.9			
Moorland Grass Mosaics	81.7	91.9	80.7			
Heath and Bog	84.7	84.6	78.8			
Tall Grass and Herb	/	/	/	/	/	/
Crops and Weeds	51.5	48.8	46.2			↓

d) Loss on ignition category

	Mean Carbon Density (t/ha)			Direction of significant changes		
LOI category (%)	1978	1998	2007	1978-1998	1998-2007	1978-2007
Mineral (0-8)	50.6	54.1	51.3	↑	↓	
Humus-mineral (8-30)	75.0	77.7	76.3			
Organo-mineral (30-60)	98.8	97.4	99.7			
Organic (60-100)	83.4	80.9	84.9			

2.3.3 Change in soil (0-15cm) C concentration and density (0-15cm) for England

Mean soil C concentrations in England ***(Table 2.6)*** are generally lower than those for GB as a whole. This is due to lower frequency of carbon rich soils in England and Wales relative to Scotland. No significant change was observed for the country between individual surveys (***Fig. 2.5a***) or the whole 29 year period (***Fig. 2.5b***).

There were fewer significant differences observed within individual vegetation and soil categories for topsoils in England relative to GB and there was an insufficient number of samples to report on some categories. Consistent with changes observed for GB were significant reductions for the Arable and Horticulture Broad Habitat and Crops and Weed Aggregate Vegetation Class. Significant differences (*** $p<0.001$) are shown (***Fig. 2.9***). Significant increases for GB woodland soils were not reflected in the results for England. However, a significant increase was observed for Infertile Grassland in England which was not observed for GB. When transformed to carbon density similar trends were observed (***Fig. 2.10***, ***Table 2.7***). Significant differences for the whole 29 year period were only observed for Crops and Weeds and Moorland Grass Mosaic Aggregate Vegetation Class.

Figure 2.9: Change in soil C concentration (0-15cm) for England between 1978 and 2007 for different AVCs. Standard errors are indicated. Significant differences (* $p<0.001$, $p<0.05$) are shown.**

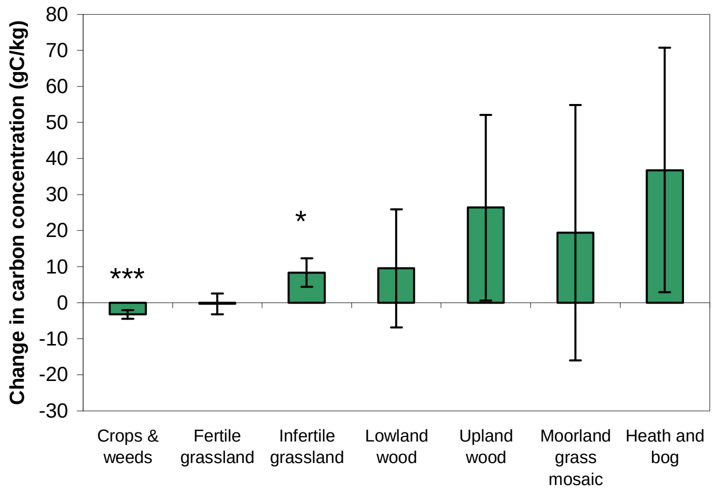


Figure 2.10: Change in soil C density (0-15cm) for England between 1978 and 2007 for different AVCs. Standard errors are indicated. Significant differences (* $p<0.001$, $p<0.05$) are shown. There was insufficient samples to report for Tall, Grass and Herb. Mean change for Upland Wood was < 0.1 g/cm^3.**

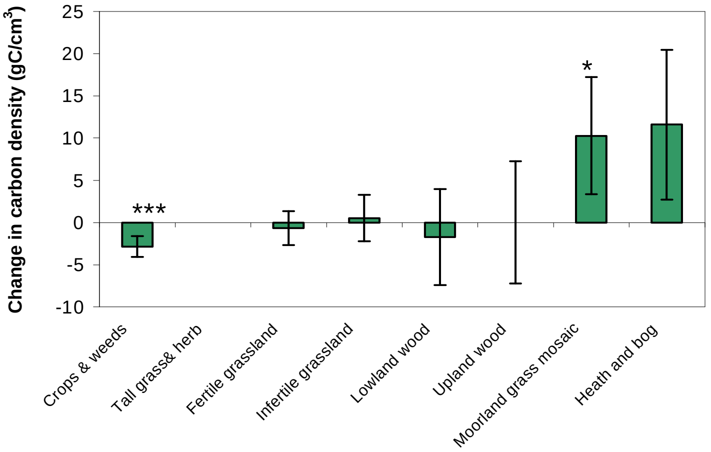


Table 2.6: Changes in soil C concentration (0-15cm) in England for (a) Broad Habitats (b) Aggregate Vegetation Class (AVC) (c) AVCs unchanged since 1978 and (d) LOI categories. Arrows denote significant change ($p<0.05$ level) in the direction shown. Diagonal line indicates too few samples to provide reliable value.

a) England - Broad Habitat

	Mean carbon concentration g/kg^{-1}			Direction of significant changes		
Broad Habitat	1978	1998	2007	1978-1998	1998-2007	1978-2007
Broadleaved, Mixed and Yew Woodland	54.6	80.4	68.7			
Coniferous Woodland	117.3	157.8	131.2			
Arable and Horticulture	33.9	32.8	30.0		↓	↓
Improved Grassland	50.3	54.2	53.1			
Neutral Grassland	60.1	69.3	64.8	↑		
Acid Grassland	197.0	200.6	209.8			
Bracken	115.0	127.3	153.5			
Dwarf Shrub Heath	298.0	227.5	229.2			
Fen, Marsh and Swamp	288.8	278.9	273.8			
Bog	197.8	431.3	398.5			
All habitat types	74.4	79.7	75.6			

b) AVC - whole dataset

	Mean carbon concentration g/kg^{-1}			Direction of significant changes		
Aggregate Vegetation Class	1978	1998	2007	1978-1998	1998-2007	1978-2007
Upland Woodland	105.0	162.5	131.3	↑		
Lowland Woodland	59.6	87.6	69.1	↑		
Fertile Grassland	45.0	50.1	44.6		↓	
Infertile Grassland	54.6	66.7	63.0	↑		↑
Moorland Grass Mosaics	198.0	189.8	217.4			
Heath and Bog	302.2	354.4	339.0			
Tall Grass and Herb	╱	43.4	43.3			
Crops and Weeds	34.0	32.3	30.7		↓	↓

c) AVC unchanged

	Mean carbon concentration g/kg^{-1}			Direction of significant changes		
Aggregate Vegetation Class	1978	1998	2007	1978-1998	1998-2007	1978-2007
Upland Woodland	╱	╱	╱	╱	╱	╱
Lowland Woodland	╱	╱	╱	╱	╱	╱
Fertile Grassland	52.1	55.0	55.7			
Infertile Grassland	63.3	74.1	72.3	↑		↑
Moorland Grass Mosaics	╱	╱	╱	╱	╱	╱
Heath and Bog	╱	╱	╱	╱	╱	╱
Tall Grass and Herb	╱	╱	╱	╱	╱	╱
Crops and Weeds	28.2	27.5	24.9		↓	↓

d) Loss on ignition category

	Mean carbon concentration g/kg^{-1}			Direction of significant changes		
LOI category (%)	1978	1998	2007	1978-1998	1998-2007	1978-2007
Mineral (0-8)	29.0	31.8	29.2	↑	↓	
Humus-mineral (8-30)	68.4	74.2	70.5			
Organo-mineral (30-60)	345.4	234.9	210.1			
Organic (60-100)	╱	╱	╱	╱	╱	╱

Table 2.7: Changes in soil C density (0-15cm) in England for (a) Broad Habitats (b) Aggregate Vegetation Class (AVC) (c) AVCs unchanged since 1978 and (d) LOI categories. Arrows denote significant change (p<0.05 level) in the direction shown. Diagonal line indicates too few samples to provide reliable value.

a) England - Broad Habitat

	Mean Carbon Density (t/ha)			Direction of significant changes		
Broad Habitat	1978	1998	2007	1978-1998	1998-2007	1978-2007
Broadleaved, Mixed and Yew Woodland	57.8	76.1	68.8	↑		↑
Coniferous Woodland	89.6	76.0	77.9			
Arable and Horticulture	49.1	49.8	46.9		↓	
Improved Grassland	62.9	68.5	64.6	↑	↓	
Neutral Grassland	62.4	65.6	65.9			
Acid Grassland	76.6	72.0	95.5		↑	↑
Bracken	95.9	72.8	94.1			
Dwarf Shrub Heath	77.1	101.8	96.6			↑
Fen, Marsh and Swamp	81.9	94.1	96.7			
Bog	106.0	119.8	85.2			↓
All habitat types	69.6	71.5	70.2	↑		

b) AVC - whole dataset

	Mean Carbon Density (t/ha)			Direction of significant changes		
Aggregate Vegetation Class	1978	1998	2007	1978-1998	1998-2007	1978-2007
Upland Woodland	81.4	68.4	81.4		↑	
Lowland Woodland	69.8	71.8	68.1			
Fertile Grassland	61.6	63.9	60.9			
Infertile Grassland	68.8	70.8	69.3			
Moorland Grass Mosaics	77.7	89.8	88.0	↑		↑
Heath and Bog	79.6	85.7	91.2			
Tall Grass and Herb	55.4	61.3	58.5			
Crops and Weeds	49.7	50.1	46.9		↓	↓

c) AVC unchanged

	Mean Carbon Density (t/ha)			Direction of significant changes		
Aggregate Vegetation Class	1978	1998	2007	1978-1998	1998-2007	1978-2007
Upland Woodland	/	/	/	/	/	/
Lowland Woodland	/	/	/	/	/	/
Fertile Grassland	63.1	69.0	68.7			
Infertile Grassland	74.5	76.0	79.5			
Moorland Grass Mosaics	/	/	/	/	/	/
Heath and Bog	/	/	/	/	/	/
Tall Grass and Herb	/	/	/	/	/	/
Crops and Weeds	49.8	47.6	43.9			↓

d) Loss on ignition category

	Mean Carbon Density (t/ha)			Direction of significant changes		
LOI category (%)	1978	1998	2007	1978-1998	1998-2007	1978-2007
Mineral (0-8)	50.4	52.3	49.6		↓	
Humus-mineral (8-30)	75.4	78.3	74.4			
Organo-mineral (30-60)	117.2	101.1	88.5		↓	↓
Organic (60-100)	/	/	/	/	/	/

2.3.4 Change in soil (0-15cm) C concentration and density (0-15cm) across Scotland

Mean soil C concentrations in Scotland are generally higher than that for GB as a whole. This is due to higher frequency of carbon rich soils relative to England and Wales. A significant increase was observed between 1978 and 1998 and a significant decline between 1998 and 2007 which was mirrored in the GB trends (***Fig. 2.5a***). There was no significant change over the whole 29 year period (***Fig. 2.5b***).

There were fewer significant differences for individual vegetation and soil categories for topsoils in Scotland relative to GB and there was insufficient number of samples to report on some categories (***Table 2.8***). Consistent with changes observed for GB were a significant increase for the Broadleaved, Mixed and Yew Woodland Broad Habitat and a significant decline in Crops and Weed Aggregate Vegetation Class (***Fig. 2.11***). Significant increases for the GB Bracken Broad Habitat was not observed for Scotland. Transformation to carbon density confirmed a significant decline in soil carbon status of the Crops and Weeds Aggregate Vegetation Class (***Fig. 2.12, Table 2.9***).

Figure 2.11: Change in soil C concentration (0-15cm) for Scotland between 1978 and 2007 for different AVCs. Standard errors are indicated. Standard errors are indicated. Significant differences (* p<0.05) are shown.

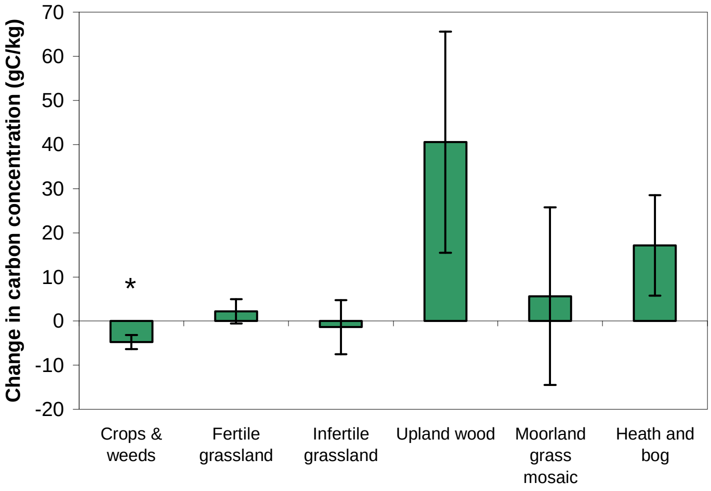


Figure 2.12: Change in soil C density for Scotland (0-15cm) between 1978 and 2007 for different AVCs. Standard errors are indicated. Standard errors are indicated. Significant differences (* p<0.005) are shown.

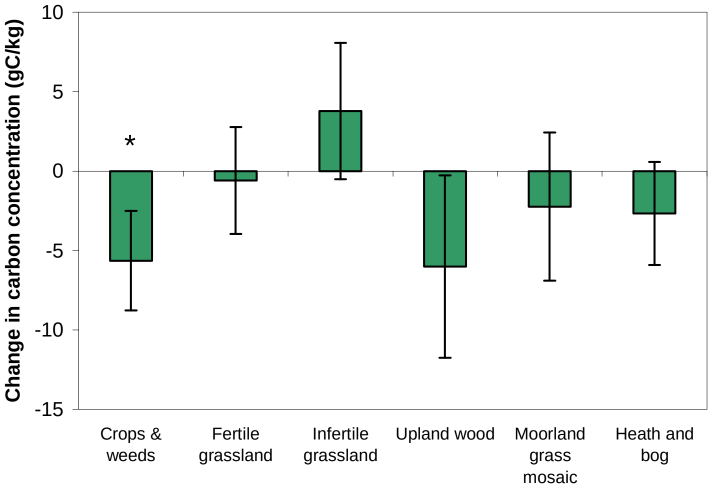


Table 2.8: Changes in soil C concentration (0-15cm) in Scotland for (a) Broad Habitats (b) Aggregate Vegetation Class (AVC) (c) AVCs unchanged since 1978 and (d) LOI categories. Arrows denote significant change ($p<0.05$ level) in the direction shown. Diagonal line indicates too few samples to provide reliable value.

a) Scotland - Broad Habitat

	Mean carbon concentration g/kg^{-1}			Direction of significant changes		
Broad Habitat	1978	1998	2007	1978-1998	1998-2007	1978-2007
Broadleaved, Mixed and Yew Woodland	88.9	171.9	145.1	↑		↑
Coniferous Woodland	238.5	245.6	228.9			
Arable and Horticulture	35.8	35.6	32.3		↓	
Improved Grassland	64.6	64.0	65.0			
Neutral Grassland	91.1	84.2	83.5			
Acid Grassland	262.8	291.9	247.9		↓	
Bracken	238.3	231.2	293.2			
Dwarf Shrub Heath	318.9	331.0	313.8			
Fen, Marsh and Swamp	214.5	270.0	228.2		↓	
Bog	424.2	453.9	438.2	↑		
All habitat types	238.5	257.8	242.0			

b) AVC - whole dataset

	Mean carbon concentration g/kg^{-1}			Direction of significant changes		
Aggregate Vegetation Class	1978	1998	2007	1978-1998	1998-2007	1978-2007
Upland Woodland	144.1	188.8	184.7			
Lowland Woodland	╱	╱	╱	╱	╱	╱
Fertile Grassland	47.0	52.5	49.2			
Infertile Grassland	84.0	89.5	82.7		↓	
Moorland Grass Mosaics	223.6	254.1	229.3			
Heath and Bog	392.6	432.9	409.7	↑	↓	
Tall Grass and Herb	╱	╱	╱	╱	╱	╱
Crops and Weeds	36.9	37.1	32.2			↓

c) AVC unchanged

	Mean carbon concentration g/kg^{-1}			Direction of significant changes		
Aggregate Vegetation Class	1978	1998	2007	1978-1998	1998-2007	1978-2007
Upland Woodland	╱	╱	╱	╱	╱	╱
Lowland Woodland	╱	╱	╱	╱	╱	╱
Fertile Grassland	╱	╱	╱	╱	╱	╱
Infertile Grassland	77.9	75.9	70.3		↓	
Moorland Grass Mosaics	280.4	320.2	288.1			
Heath and Bog	416.8	457.4	440.9	↑		
Tall Grass and Herb	╱	╱	╱	╱	╱	╱
Crops and Weeds	╱	╱	╱	╱	╱	╱

d) Loss on ignition category

	Mean carbon concentration g/kg^{-1}			Direction of significant changes		
LOI category (%)	1978	1998	2007	1978-1998	1998-2007	1978-2007
Mineral (0-8)	30.5	33.6	31.4	↑	↓	
Humus-mineral (8-30)	87.7	88.2	85.9			
Organo-mineral (30-60)	255.8	288.8	232.9		↓	
Organic (60-100)	447.5	482.0	468.6	↑		

Table 2.9: Changes in soil C density (0-15cm) in Scotland for (a) Broad Habitats (b) Aggregate Vegetation Class (AVC) (c) AVCs unchanged since 1978 and (d) LOI categories. Arrows denote significant change (p<0.05 level) in the direction shown. Diagonal line indicates too few samples to provide reliable value.

a) Scotland - Broad Habitat

	Mean Carbon Density (t/ha)			Direction of significant changes		
Broad Habitat	1978	1998	2007	1978-1998	1998-2007	1978-2007
Broadleaved, Mixed and Yew Woodland	75.2	62.9	77.6			
Coniferous Woodland	87.4	79.3	80.4			
Arable and Horticulture	53.6	52.6	52.3			
Improved Grassland	68.8	72.4	70.1			
Neutral Grassland	72.8	71.3	73.9			
Acid Grassland	93.8	93.7	88.4			
Bracken	68.2	94.4	87.4	↑		
Dwarf Shrub Heath	88.1	82.1	90.0			
Fen, Marsh and Swamp	93.0	94.8	76.6			
Bog	83.4	88.3	83.3			
All habitat types	77.6	78.0	78.7			

b) AVC - whole dataset

	Mean Carbon Density (t/ha)			Direction of significant changes		
Aggregate Vegetation Class	1978	1998	2007	1978-1998	1998-2007	1978-2007
Upland Woodland	87.8	79.9	81.8			
Lowland Woodland	0.0	0.0	0.0			
Fertile Grassland	66.1	69.7	65.5			
Infertile Grassland	69.0	77.9	72.8	↑		
Moorland Grass Mosaics	92.6	91.6	90.4			
Heath and Bog	85.3	83.6	82.6			
Tall Grass and Herb	/	/	/	/	/	/
Crops and Weeds	56.3	58.3	50.7		↑	↓

c) AVC unchanged

	Mean Carbon Density (t/ha)			Direction of significant changes		
Aggregate Vegetation Class	1978	1998	2007	1978-1998	1998-2007	1978-2007
Upland Woodland	/	/	/	/	/	/
Lowland Woodland	/	/	/	/	/	/
Fertile Grassland	/	/	/	/	/	/
Infertile Grassland	68.2	67.8	72.0			
Moorland Grass Mosaics	89.7	90.3	87.8			
Heath and Bog	85.2	86.9	81.6			
Tall Grass and Herb	/	/	/	/	/	/
Crops and Weeds	/	/	/	/	/	/

d) Loss on ignition category

	Mean Carbon Density (t/ha)			Direction of significant changes		
LOI category (%)	1978	1998	2007	1978-1998	1998-2007	1978-2007
Mineral (0-8)	49.9	52.2	52.0			
Humus-mineral (8-30)	77.8	80.6	81.5			
Organo-mineral (30-60)	100.9	93.1	89.9			
Organic (60-100)	85.8	77.5	85.3	↓		

2.3.5 Change in soil (0-15cm) C concentration and density (0-15cm) across Wales

Mean soil C concentrations (0-15cm) in Wales are intermediate relative to England and Scotland. No significant change between surveys or over the whole 29 year period was observed (***Fig. 2.5 a & b***).

There was only one significant difference observed within individual categories; a decrease for the Coniferous Woodland Broad Habitat (***Table 2.10***). There was no significant change with the two Aggregate Vegetation Classes we are able to report either for soil (0-15cm) concentration or density (***Fig. 2.13 & 2.14***, ***Table 2.10 & 2.11***). The low number of reporting categories are due to the lower number of samples for Wales relative to England and Scotland which were sampled in 1978. Reporting change over the full 29 year reporting period is therefore only possible for Fertile and Infertile Grasslands which have the largest number of sample squares. The increase in sample number in 2007 survey will ensure this improves in future surveys as we now have baseline measurements for 7 Broad Habitat categories.

Figure 2.13: Change in soil C concentration (0-15cm) for Wales between 1978 and 2007 for the AVC categories with sufficient sample number to allow reporting for the full 29 year reporting period. No significant change was observed.

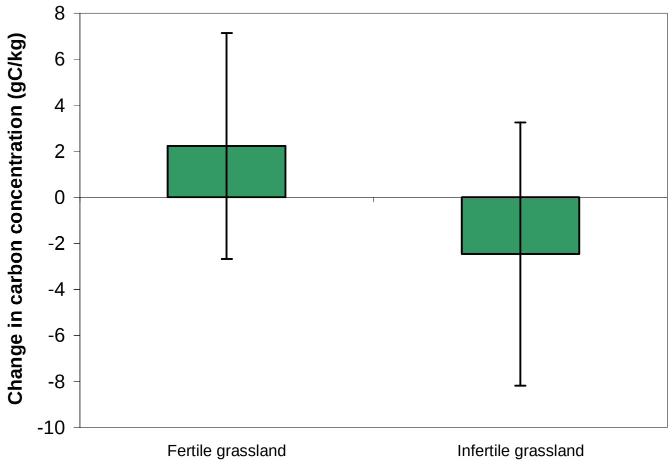


Figure 2.14: Change in soil C density (0-15cm) for Wales between 1978 and 2007 for the AVC categories with sufficient sample number to allow reporting for the full 29 year reporting period. Standard error bars are indicated. No significant change was observed.

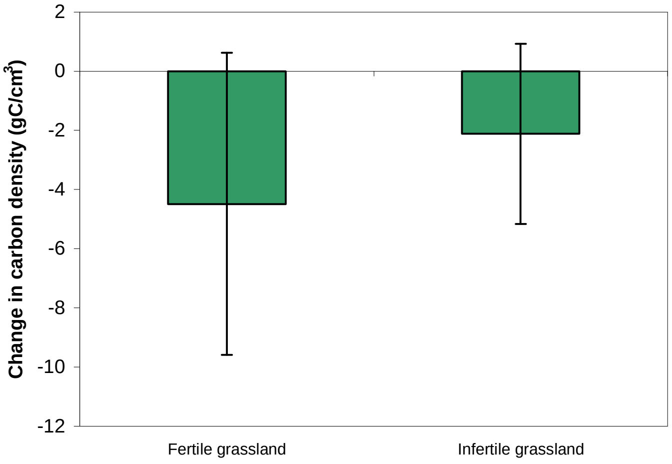


Table 2.10: Changes in soil C concentration (0-15cm) in Wales for (a) Broad Habitats (b) Aggregate Vegetation Class (AVC) (c) AVCs unchanged since 1978 and (d) LOI categories. Arrows denote significant change ($p<0.05$ level) in the direction shown. Diagonal line indicates too few samples to provide reliable value.

a) Wales - Broad Habitat

	Mean carbon concentration g/kg^{-1}			Direction of significant changes		
Broad Habitat	1978	1998	2007	1978-1998	1998-2007	1978-2007
Broadleaved, Mixed and Yew Woodland	67.2	72.1	87.0			
Coniferous Woodland	176.6	233.6	184.3		↓	
Arable and Horticulture	38.5	/	34.9			
Improved Grassland	68.0	66.3	60.6			
Neutral Grassland	53.3	57.4	62.1			
Acid Grassland	198.2	208.2	207.7			
Bracken	/	/	/	/	/	/
Dwarf Shrub Heath	210.7	267.2	280.0			
Fen, Marsh and Swamp	/	/	/	/	/	/
Bog	/	/	/	/	/	/
All habitat types	107.6	108.9	108.6			

b) AVC - whole dataset

	Mean carbon concentration g/kg^{-1}			Direction of significant changes		
Aggregate Vegetation Class	1978	1998	2007	1978-1998	1998-2007	1978-2007
Upland Woodland	/	/	142.4			
Lowland Woodland	/	/	/	/	/	/
Fertile Grassland	54.5	53.9	56.8			
Infertile Grassland	63.7	63.2	61.2			
Moorland Grass Mosaics	/	/	220.8			
Heath and Bog	/	/	333.8			
Tall Grass and Herb	/	/	/	/	/	/
Crops and Weeds	/	/	/	/	/	/

c) AVC unchanged

	Mean carbon concentration g/kg^{-1}			Direction of significant changes		
Aggregate Vegetation Class	1978	1998	2007	1978-1998	1998-2007	1978-2007
Upland Woodland	/	/	/	/	/	/
Lowland Woodland	/	/	/	/	/	/
Fertile Grassland	/	/	/	/	/	/
Infertile Grassland	/	/	/	/	/	/
Moorland Grass Mosaics	/	/	/	/	/	/
Heath and Bog	/	/	/	/	/	/
Tall Grass and Herb	/	/	/	/	/	/
Crops and Weeds	/	/	/	/	/	/

d) Loss on ignition category

	Mean carbon concentration g/kg^{-1}			Direction of significant changes		
LOI category (%)	1978	1998	2007	1978-1998	1998-2007	1978-2007
Mineral (0-8)	/	/	/	/	/	/
Humus-mineral (8-30)	71.4	68.8	69.1			
Organo-mineral (30-60)	/	/	/	/	/	/
Organic (60-100)	/	/	/	/	/	/

Table 2.11: Changes in soil C density (0-15cm) in Wales for (a) Broad Habitats (b) Aggregate Vegetation Class (AVC) (c) AVCs unchanged since 1978 and (d) LOI categories. Arrows denote significant change ($p<0.05$ level) in the direction shown. Diagonal line indicates too few samples to provide reliable value.

a) Wales - Broad Habitat

	Mean Carbon Density (t/ha)			Direction of significant changes		
Broad Habitat	1978	1998	2007	1978-1998	1998-2007	1978-2007
Broadleaved, Mixed and Yew Woodland	77.2	61.4	79.0	↓		
Coniferous Woodland	65.7	94.0	76.2			
Arable and Horticulture	70.8	/	56.0			
Improved Grassland	72.6	69.0	68.1			
Neutral Grassland	64.4	67.1	69.4			
Acid Grassland	89.2	92.8	83.8			
Bracken	/	/	/	/	/	/
Dwarf Shrub Heath	134.1	106.8	103.3			↓
Fen, Marsh and Swamp	/	/	/	/	/	/
Bog	/	/	/	/	/	/
All habitat types	76.5	80.2	75.2			

b) AVC - whole dataset

	Mean Carbon Density (t/ha)			Direction of significant changes		
Aggregate Vegetation Class	1978	1998	2007	1978-1998	1998-2007	1978-2007
Upland Woodland	/	/	/	/	/	/
Lowland Woodland	/	/	/	/	/	/
Fertile Grassland	73.1	71.4	68.6			
Infertile Grassland	71.8	66.3	69.7	↓		
Moorland Grass Mosaics	/	/	/	/	/	/
Heath and Bog	/	/	/	/	/	/
Tall Grass and Herb	/	/	/	/	/	/
Crops and Weeds	/	/	/	/	/	/

c) AVC unchanged

	Mean Carbon Density (t/ha)			Direction of significant changes		
Aggregate Vegetation Class	1978	1998	2007	1978-1998	1998-2007	1978-2007
Upland Woodland	/	/	/	/	/	/
Lowland Woodland	/	/	/	/	/	/
Fertile Grassland	/	/	/	/	/	/
Infertile Grassland	/	/	/	/	/	/
Moorland Grass Mosaics	/	/	/	/	/	/
Heath and Bog	/	/	/	/	/	/
Tall Grass and Herb	/	/	/	/	/	/
Crops and Weeds	/	/	/	/	/	/

d) Loss on ignition category

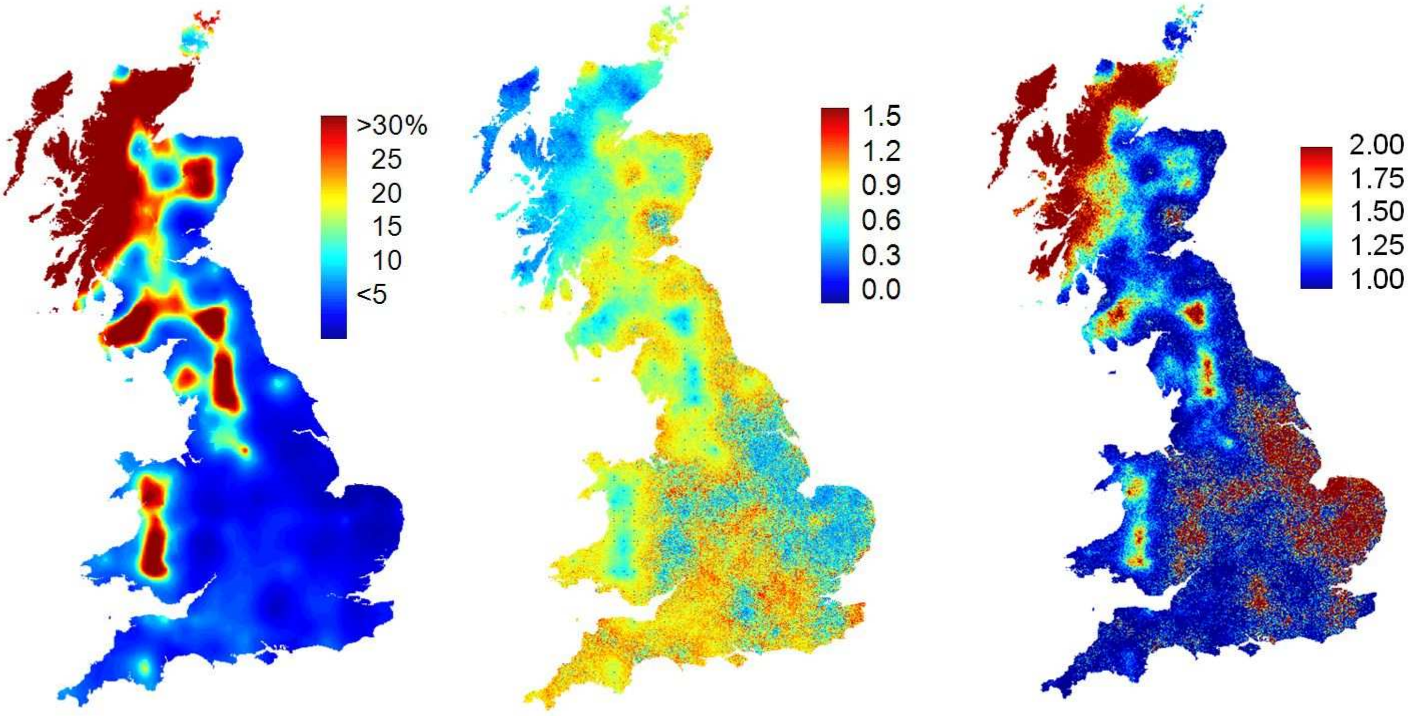
	Mean Carbon Density (t/ha)			Direction of significant changes		
LOI category (%)	1978	1998	2007	1978-1998	1998-2007	1978-2007
Mineral (0-8)	/	/	/	/	/	/
Humus-mineral (8-30)	71.8	79.5	80.0	↑		↑
Organo-mineral (30-60)	/	/	/	/	/	/
Organic (60-100)	/	/	/	/	/	/

2.4 Discussion

It is estimated that European soils contain 75-79Pg C (Schils *et al.*, 2008), of which UK soils store 6-7 Pg. The top 15 cm of soils in GB (i.e. the UK without Northern Ireland) store ca. 1.6 Pg C (***Table 2.11***). Soils are the largest terrestrial pool of C. There is a need to track and understand trends in soil C, and to optimise future soil C storage through land management and use. Although measurements of topsoil organic C are available in all member EU countries, very few countries have repeated sampling campaigns (Saby *et al.*, 2008) and to our knowledge, Countryside Survey is the first survey in Europe to sample soils three times. The approach to monitoring programs in Europe has been reviewed by Kibblewhite *et al.* (2008), Morvan *et al.* (2008) and Schils *et al.* (2008); current national monitoring programs are criticised because of lack of soil BD measurements, insufficient sample numbers and lack of repeated explanatory measurements. Countryside Survey, particularly the 2007 Survey, addresses these particular issues for GB.

The mapped distributions of soil C concentrations (as %) in 2007 (***Fig. 2.15a***) follows the anticipated pattern with high concentrations in upland peatland areas such as NW Scotland, N England and upland areas of Wales. The coefficient of variation (CV, standard deviation / mean, an indicator of the spread of the data around the mean value) is lowest in areas dominated by either low carbon soils which are intensively managed or high carbon soils in upland areas where there is little variation (***Fig. 2.15b***). Conversely, the signal to noise ratio (SNR, mean / standard deviation) indicates that for values above 1 the signal is stronger than the noise. High SNR's are consistent with managed arable areas across Eastern England and the upland and peat areas across the UK but especially in N Scotland *(**Fig. 2.15c**)*. This may occur because the soil management leads to greater uniformity of carbon levels across these areas. In areas less intensively managed, natural variation in soil carbon levels across the landscape may lead to the low SNR's observed.

Figure 2.15: Maps of soil %C concentration (0-15cm) in 2007(a) using ordinary Kriging (%C), (b) coefficient of variation and (c) signal to noise ratio.



Multiplying soil C density by area of habitats for individual countries results in the estimate of carbon currently stored in 0-15cm of GB soils (***Table 2.11***).

Table 2.11: Estimate of soil carbon stock (0-15cm) for GB and individual countries.

Country	km^2	Soil C density (0-15cm) t/ha	Soil C stock (0-15cm) TgC	s.e.
GB	228226	69.31	1582	29
England	127284	62.45	795	15
Scotland	79849	78.79	628	11
Wales	21091	75.19	159	3

The CS estimate for England and Wales (954 Tg) in soils (0-15cm) compares with an estimate of 864 Tg for England and Wales estimated by Bellamy *et al.* (2005). One major cause of this difference is the new conversion factor for LOI to soil C concentration of 0.55 defined by CS compared to the factor of 0.5 used by Bellamy *et al.* (2005). The new pedotransfer function for bulk density measurements to soil C concentration described in Chapter 1 primarily affects estimates of stock and change for organic soils only and has only limited effect on total stock estimates (0-15cm) at the national scale.

The results from the Countryside Survey of Great Britain reported here suggest that the topsoil C concentration and stock of GB and its constituent countries has not changed significantly since 1978. Results for topsoil C density are a combination of changes in soil C concentration and estimated bulk density, and we observed no overall change at a GB level in C concentration, although there was a significant increase (+8%) between 1978 and 1998 and a decrease (-6.5%) in 1998 and 2007. Examining C concentration by other strata (e.g. country, soil C group, AVC) produced similar results, with consistent differences between 1978 and 2007 only occurring in arable and woodland systems. Particularly significant in light of Bellamy *et al.* (2005) is the lack of change in topsoil C concentrations in organic soils; although this disagrees with Bellamy *et al.* (2005), it is in agreement with other reports and the outputs of soil C models.

There are unfortunately few monitoring studies from W. Europe with which to compare our topsoil results; some studies only report changes in C concentration, some only C density, some only to 1m depth. Our results for changes in topsoil C concentrations in arable and grassland systems are comparable with the ranges reported by various studies on Belgian soils (Goidts and van Wesemael, 2007), but are smaller than those reported by Bellamy *et al.* (2005) for England and Wales. For woodland soils, CS estimates of change are larger than those reported from a major UK resurvey of 103 woodlands (Kirby *et al.*, 2005), and in the opposite direction to reports of C changes in woodland soils in Belgium (Stevens and van Wesemael, 2008), and to that of Bellamy *et al.* (2005) for England and Wales. Given the small number of woodlands sampled in CS in 1978 and 1998, a potentially more accurate picture of changes in topsoil C concentration in GB woodlands was reported by Kirby *et al.* (2005), whose survey specifically examined changes in woodlands between 1971 and 2000-2003 and found no significant change in topsoil C concentration, which remained around 88 g C kg^{-1}. However, CS estimates of changes in woodland topsoil C densities (12-30 g C m^{-2} yr^{-1}) are similar to model estimates of European forest soils by Liski et al., (2002) and Nabuurs et al., (2003), which suggest net sequestration of 19 and 11 g m^{-2} yr^{-1}, respectively.

A range of potential factors responsible for soil C change have been proposed, including climate change, nutrient deposition, management practices, increasing atmospheric CO_2 concentrations, and land use and land use change. However, at the large scale the attribution of change is complicated by the presence of multiple drivers which can simultaneously affect the balance of C inputs (largely plant biomass) and outputs (mostly microbial respiration). Our results also suggest that land use change (as measured by the AVC) is not responsible for the few significant observed changes in topsoil C concentration. Climate change is unlikely to be the cause of change in topsoil C, since changes in temperature and rainfall across GB since

1978 have been insufficient to cause large-scale changes in mineral soil C concentration or density (Smith *et al.*, 2007). Model estimates of climate change-related variation in C density for England, Scotland and Wales are -0.01, +0.03 and +0.01 %yr-^{1}, respectively, if changes in net primary productivity (NPP) are included (Smith *et al.*, 2007). CS estimates of change are much larger than these: -0.09 to -0.21, +0.1 to +0.13 and +0.18 to +0.39 %yr^{-1} for all arable, grassland and forest soils, respectively, across GB. Since land use change and climate change may be excluded as primary drivers of change, and trends differ between habitat types, other habitat-specific drivers must be responsible for the long-term changes observed in arable and woodland soils. The most consistent finding from CS in 2007 is the reduction in soil C (0-15cm) concentration and density in cropland. A reduction in mean total N concentration as well (Chapter 4) suggests processes such as erosion, deep ploughing (which brings soil with lower C:N ratio soil to the surface) and/or increased decomposition may be responsible for this trend. Intensification of farming practices are often thought to be the dominant factor (Stoate *et al.* 2001). In Broadleaved Woodland where a significant increase was observed, changes in tree age structure and reduced harvesting are likely to be the main drivers of soil C concentration increases (Liski *et al.*, 2002; De Vries *et al.*, 2006). Efforts to attribute the observed soil (0-15cm) C changes in CS are ongoing and will be reported in the CS Integrated Assessment Report.

2.5 Policy Implications

The results from CS in 2007 do not confirm the widespread loss of soil carbon (0-15cm) as reported by Bellamy *et al*. (2005) for soils (0-15cm) as part of the National Soils Inventory monitoring programme in England and Wales between 1978 and 2003. The one consistent exception is loss of carbon (0-15cm) from the intensively managed Arable and Horticulture Broad Habitat / Crops and Weeds Aggregate Vegetation Class soils. This suggests that current policies in place to limit soil degradation are not maintaining soil quality in cropped land.

The stability in soil carbon measurements in other land use types could be a combination of a complex mix of factors some of which may increase soil (0-15cm) C concentration e.g. increased carbon inputs from plants due to nitrogen deposition and increased carbon dioxide in the atmosphere, whilst some may reduce soil C concentration e.g. intensive land management. Only by further analysis of the spatial patterns within the CS datasets in combination with experimental and survey data from other studies and modelling approaches will it be possible to advise on the likely future trends of soil carbon and indeed help to explain the general trend of an increase between 1978 and decrease from 1998 to 2007. It should also be remembered these are results for soil 0-15cm only and not the whole soil profile. It does not include soil lost by erosion although a reduction in soil C concentration would be expected if the latter was widespread as soil decreases in soil C concentration down the soil profile.

A major change for CS in 2007 was the introduction of data which enables calculation of carbon stock (0-15cm). This takes into account not only the soil C concentration of soil in the top 15cm but also the amount of soil. The amount of soil may change due to changes in the compaction of the soil for example due to the use of heavy machinery or increased animal numbers. The increased information this provides has resulted in greater confidence in the reduction in soil carbon for intensively managed arable and crop soils as this trend is observed in both soil C concentration and C density results and is the most consistent result within individual categories. By combining C density data with areas of Broad Habitats a national estimate of the topsoil (0-15cm) carbon stock from co-located bulk density and soil C concentration measurements is now available for the first time.

The data provide an evidence base for monitoring the protection of soil carbon stores highlighted as a priority within the new Soils Strategy for England, the Environment Strategy in Wales and Scottish Soil Framework. The new data have now been selected as an indicator of soil quality for State of the Environment Reporting.

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3. Soil pH

Summary

- **The mean pH of soils (0-15cm) increased in less acidic soils across Great Britain (GB) between 1998 and 2007 continuing a trend observed between 1978 and 1998. These soils are associated with Broadleaved Woodland, Arable and Horticulture, Improved Grassland and Neutral Grassland Broad Habitats. This increase in pH is consistent with the expected benefit of continued reductions in sulphur emissions.**
- **There was no significant change in mean soil (0-15 cm) pH in more acidic, organic-rich soils across Great Britain between 1998 and 2007. This will affect Broad Habitats such as Bog, Dwarf Shrub Heath and Acid Grassland. Data analysis is ongoing to determine if the lower sulphur reductions in the north and west of the Great Britain or other drivers of change such as nitrogen deposition and land management are responsible in the organic soils where pH did not significantly increase between 1998 and 2007. Conversion between land uses between surveys was not responsible as similar trends were observed in soils with or without conversion.**
- **One exception with no apparent trends between any time period was Coniferous Woodland. It is possible the acidification of soils associated with intensive forestry due to base cation uptake and enhanced capture of acidic pollutants by the tree canopy may be offsetting the effects of reduced sulphur emissions.**
- **The results for individual countries broadly reflected those for Great Britain as a whole with continued increase in soil pH only observed in less acidic soils. Insufficient sample size for some habitat types with lower area in individual countries prevented significant trends being identified in some cases.**
- **The implications of these findings are that current emission control policies combined with current policies to protect soil through sustainable land management practices have had some major benefits but they may not be sufficient to promote continued recovery from acidification in organic-rich soils.**

3.1 Policy background

Key question: Has the recovery from acidification detected by Countryside Survey between 1978 and 1998 continued?

Measurements: The pH of soils (0-15 cm) from all plots sampled in 1978 and 1998 and all additional plots sampled in 2007.

Soil pH is probably the most commonly measured soil chemical parameter. It gives an indication of soil acidity and therefore has direct policy relevance in a number of areas primarily recovery from acidification and impacts on biodiversity. Soil pH is a key variable for predicting the mobility and bioavailability of metals in soils and helps determine the response of plant species to changes in atmospheric nitrogen and acid deposition. It is currently estimated that 58% of terrestrial semi-natural habitats across GB receive acidic deposition in excess of their buffering capacity thus potentially causing long term damage according to the critical load methodology (RoTAP 2010).

The soil pH data from the Countryside Survey in 1998 provided unique nationwide evidence of soil pH change (0-15 cm) since the first measurements in 1978. Preliminary data were incorporated within the report of the National Expert Group on Transboundary Air Pollution (NEGTAP, 2001) as providing evidence of a possible response to the reduction in acid deposition over the twenty year period between the two surveys. The MASQ report (Monitoring and Assessing of Soil Quality; Black *et al.*, 2000) provided a more complete analysis of the Countryside Survey soils data and confirmed an increase in soil pH (0-15 cm) between 1978 and 2000 in all but Coniferous Woodlands Broad Habitat, irrespective of whether the data were analysed by Environmental Zone, Broad Habitat, ITE Land Class, Aggregate Vegetation Class (AVC) or major soil group. More importantly, the vegetation survey indicated a change in vegetation structure towards more nitrophilous, less acid tolerant species from 1990 to 1998 (Haines-Young *et al.*, 2000) providing corroboration for the soil data and an excellent example of the power of the Countryside Survey approach in combining co-located, synchronous data collection of a wide range of variables. A new review of changes in soil pH is due to be published later in 2010; Review of Transboundary Air Pollution (RoTAP) and current indications are that trends identified by CS are mirrored in other surveys (RoTAP, 2010).

The rationale for including measurement of soil pH at 0-15 cm depth in the survey in 2007 is summarised in ***Table 3.1***. Measurement of soil (0-15 cm) pH will deliver:

- An extended time series of soil pH from 1978,
- Increased reporting power for individual countries (especially Wales) by making measurements in all squares sampled during Countryside Survey in 2007 (591).
- An assessment as to whether the decrease in soil acidity across all major soil groups and the majority of Broad Habitats observed between 1978 and 1998 has continued,
- Improved prediction of plant species composition change using linked biogeochemical / plant species models,

3. Soil pH

Table 3.1: Rationale for measurement of soil (0-15 cm) pH.

Issue	Facts	Comments
History in Countryside Survey	Measured on soils collected from Main Plots in the original 256 squares which formed the "ITE Ecological Survey of the UK". Countryside Survey in 1998 re-measured pH from the same 256 squares.	256 squares essential to maintain time series data. 591 squares will provide better spatial information. Soil pH is a critical interpretative variable.
Country level reporting	Power analysis has indicated only 256 squares are needed to quantify pH change at country level based on change between 1978 and 1998.	It is unlikely that the pH change between Countryside Survey in 1998 and Countryside Survey in 2007 will be as great or consistent as between 1978 and Countryside Survey in 1998. The time period is shorter and the deposition change has been less. Soil pH is a critical parameter for interpretation of plant species change (Ellenberg pH), bioavailability of P, N and metals. Recommendation is therefore for soil pH (0-15 cm) to be measured in all 591 squares.
Links and compatibility to other monitoring programmes	Comparable data to those collected in the National Soil Inventory (NSI), Representative Soil Sampling Scheme (RSSS) for same horizon (0-15cm). Environmental Change Network (ECN) provides more information to depth and more frequent monitoring of soil solution but from few sites.	Countryside Survey will provide data for three time points. There were partial resurveys of the NSI in 1994/5, 1995/6 and 2003. RSSS have data reported to 2001. Soil pH was measured at many ECN sites in 1993, 1998 and 2003. Countryside Survey in 2007 will provide the only update for spatially extensive data on soil pH (0-15 cm) in Great Britain. A comparison of these surveys was reported in Defra project SP0515 (Defra 2003).
Uniqueness of Countryside Survey	Time series is unique. The integrated approach enabling links to vegetation, management and water quality change is unique.	
Value for money (Policy priority or interpretative value x cost)	Very high	High policy and interpretative value, low cost.

3.2 Methods

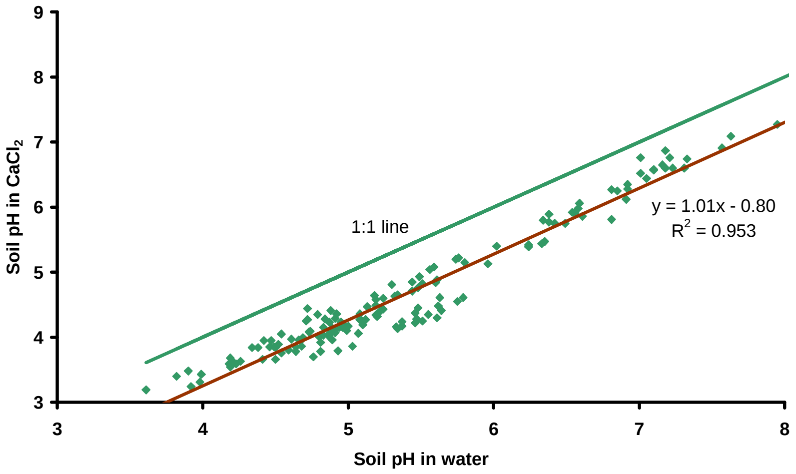
3.2.1 Proof of concept

The measurement of soil pH in a suspension of de-ionised water is a very well established technique and was used in both 1978 and for Countryside Survey in 1998. However, measurements of pH in water are subject to a number of uncertainties some of which are fundamentally related to the effects of changes in the ionic strength of the soil-water suspension on ions sorbed to the soil particles. One of the main consequences of this is the so called dilution effect, whereby different pH values are measured depending on the soil:water ratio in the suspension. A solution of 0.01M Calcium Chloride ($CaCl_2$) has approximately the same ionic strength as the soil solution in fertilised temperate soils and has been recommended as a more appropriate medium for soil pH measurement (Schofield and Taylor, 1955). Measurement of pH in $CaCl_2$ yields more consistent results; the pH value in $CaCl_2$ is lower than measured in water but closer to the value observed under equilibrium conditions using repeated extractions (White, 1969). The relationship between soil pH measured in water and $CaCl_2$ is not consistent. For example, over a wide pH range in lowland grassland soils ***(Fig. 3.1)***, soil pH in $CaCl_2$ was approximately 0.8 pH units lower than the corresponding measurements in deionised water. There was also considerable scatter in the relationship, particularly for more acid soils.

In the 1978 Ecological Survey, soil pH in water was measured at ITE Bangor using a modified version of the method used by the Soil Survey of England and Wales (Avery and Bascomb, 1974). In 1998, soil pH was measured at CEH Merlewood using the protocol described in Allen *et al.*, (1989). The latter resulted in a suspension with a soil to water ratio of approximately 1:2 by weight compared to the 1978 analyses with a soil to water ratio of 1:2.5 by weight. It is unlikely that this small difference in ratio resulted in a significant difference in pH between the two methods. As soil pH in $CaCl_2$ was to be measured in 2007, in addition to pH in water, the original method used in 1978 was chosen. Soil pH in $CaCl_2$ can easily be measured using the 1978 method by adding a few millilitres of concentrated $CaCl_2$ solution to the water pH suspension. This saves the time required to re-weigh and mix a second sample and conserves valuable soil for other analyses.

The comparability of the 1978 and 1998 methods was checked prior to the survey in 1998 using archive soils taken in 1971 from woodland habitats across Great Britain (Black *et al.*, 2000). The method used in 1971 was the same as that used in 1978 and the re-analysis on dried archived soils used the 1998 method. No statistically significant differences were found between pH values measured on dried archive soils from 1971 using the 1998 method and the original data obtained from field moist soils in 1971.

Figure 3.1: Soil pH (0-15 cm) measured in deionised water and 0.01M $CaCl_2$ for a range of lowland grassland soils (unpublished data CEH Bangor and CCW).



3.2.2 *Laboratory analysis*

Samples for soil pH measurement were collected using the 15 cm long by 5 cm diameter black plastic core following the field protocol described in the Soils Manual (Emmett *et al.*, 2008).

The pH of fresh soil in water was measured using 10 g of field-moist soil in a 50 ml plastic beaker to which 25 ml of deionised water was added giving a ratio of soil to water of 1:2.5 by weight. The suspension was stirred thoroughly and left to stand for 30 minutes after which time the pH electrode was inserted into the suspension and a reading taken after a further 30 seconds. Following the measurement of soil pH in water, 2 ml of 0.125M $CaCl_2$ were added to the suspension, which on dilution with the 25 ml of water resulted in a solution concentration of approximately 0.01M $CaCl_2$. The suspension was stirred thoroughly and left for 10 minutes after which time the pH electrode was inserted into the suspension and a reading taken after a further 30 seconds. Measurements of soil pH in water and $CaCl_2$ were repeated on all samples using 10 g of air dried < 2mm sieved soil.

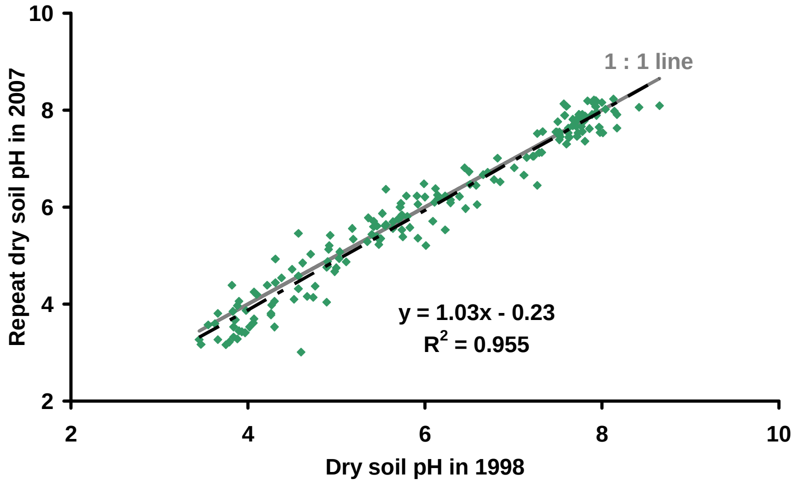
The fresh soil pH measurements were made as soon as possible after the sample was opened. Care was taken to ensure that the temperature of the buffer solutions used to calibrate the pH meter differed by no more than 1℃ from the temperature of the soil suspensions. The pH electrode was carefully rinsed and dried between each measurement. Particular care was taken to clean the electrode following calibration with buffer solutions.

3.2.3 *Quality Assurance and Quality Control*

The Defra/NERC/BBSRC Joint Codes of Practice were followed.

Method comparability: Soil pH measurements in deionised water were made on a subset of approximately 200 soils taken from the 1998 soil sample archive to check the comparability of the method used in 2007 with that used in 1998.

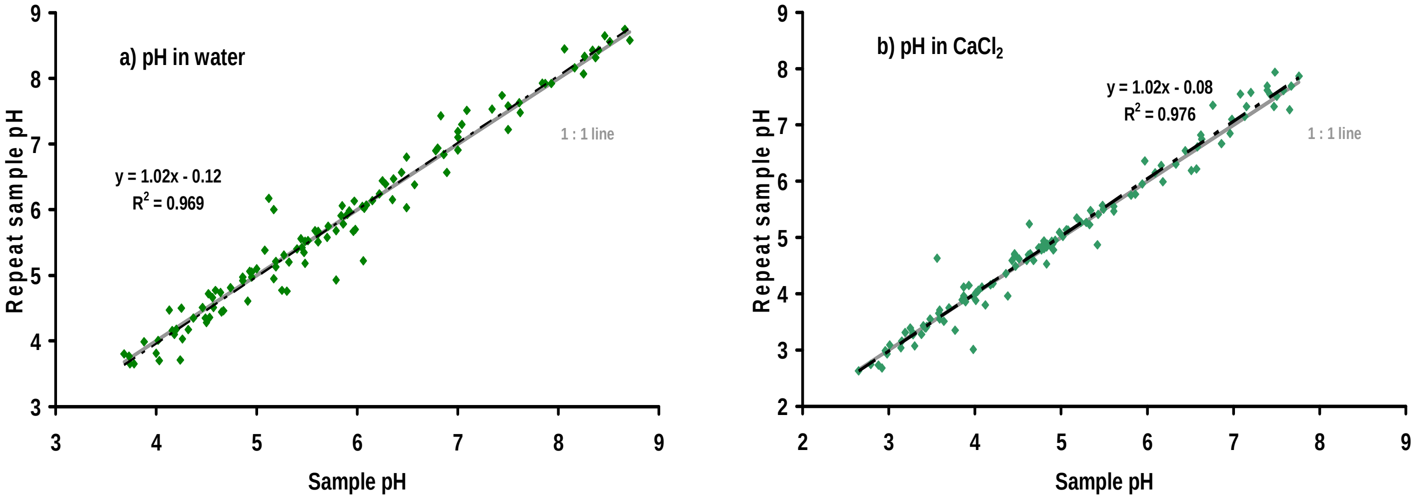
Figure 3.2: Results of repeat soil pH measurements on archived air dried soil samples collected in 1998.



A plot of the repeated measurements from 1998 survey ***(Fig. 3.2)*** shows close agreement between the two datasets with no discernible bias and points clustering along the 1:1 line. From these data, it was concluded that the difference between the methods used in 1998 and 2007 / 1978 would not bias the pH time series data. However, it was noted that in 1978, soil pH was reported to 0.05 pH units whereas in 1998 and 2007 data were reported to 0.01 pH units.

Analytical Quality Control: The calibration of the pH meter was checked after a batch of 25 samples using pH 4 and pH 7 buffer solutions. If either of the buffer solution calibration values differed by more than 0.02 pH units from the expected value, the meter was re-calibrated. A standard soil, a certified reference soil and a duplicate analysis was performed on every batch of 25 samples ***(Fig. 3.3)***. Soil pH in water and $CaCl_2$ was reported to 0.01 pH units.

Figure 3.3: Results for batch repeats of pH measurements in a) water and b) $CaCl_2$.



3.2.4 Reporting

Soil pH data (0-15 cm) have been analysed to provide information on the state of soil acidity in 2007 and the change in soil acidity since 1978. The statistical approach used for analysing the data for change involved bootstrapping which allows for non-normality in the data without the necessity of knowing details of the actual distribution. As such it provides a more accurate measurement of significance. Annex F of Emmett *et al.* (2008) provides a background document describing this approach.

Prior to the 2007 survey, a power analysis was undertaken of the sampling requirements to reliably detect change in soil pH (0-15 cm) at the country level and details of the outcome are included in Emmett *et al.* (2008). The resulting increase in the number of squares for Countryside Survey in 2007 to 591 has enabled reporting of soil pH by Broad Habitat at the Great Britain level (Carey *et al.*, 2008) and at the level of the individual countries (Smart *et al.*, 2009 for Wales; Norton *et al.*, 2009 for Scotland; Countryside Survey, 2009 for England).

The data in this report describe soil acidity in 2007 and change since 1978 by Broad Habitat, Aggregate Vegetation Class and Loss-on-Ignition (LOI) class. In summary:

- Broad Habitat - The Broad Habitat classification consists of 27 habitats which account for the entire land surface of Great Britain, and the surrounding sea. Countryside Survey reports on soils for 10 major terrestrial habitats.
- Aggregate Vegetation Class (AVC) – is a high level grouping of vegetation types produced from a quantitative hierarchical classification of the different plant species found in the original Countryside Survey sample plots.
- Loss on ignition (LOI) category – soil type based on soil organic matter content defined as mineral (0-8% LOI; 0-44 g C kg^{-1}), humus-mineral (8 – 30% LOI ; 44-165 g C kg^{-1}), organo-mineral (30 – 60% LOI; 165-330 g C kg^{-1}) and organic (60 – 100%; > 330 g C kg^{-1}).

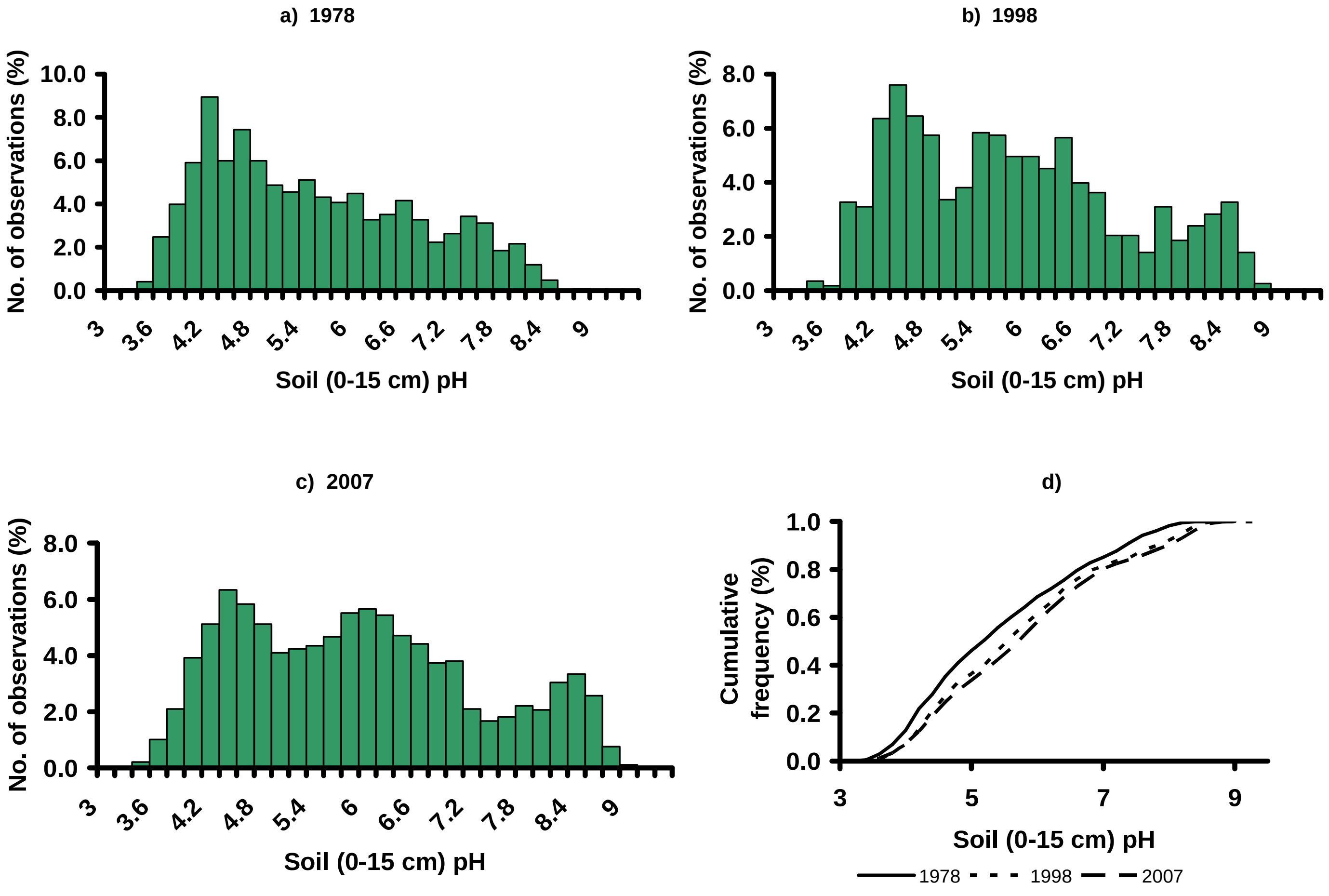
The soil pH data were mapped using kriging to interpolate between the Countryside Survey sample points. Routine checking of data for outliers was conducted and the working dataset was transformed using a normal score procedure to obtain a Gaussian distribution. The data were then interpolated on a 1km UK grid using ordinary kriging and finally, the kriged data were back-transformed to produce an interpolated map of soil pH. Prior to the 2007 survey, data were too sparse to give meaningful and statistically valid interpolation in space and thus no maps of change are presented. This will be possible in future surveys due to the enhanced baseline.

3.3 Results

3.3.1 Structure of the soil pH data

The measured soil pH (0-15 cm) across the three surveys ranged between pH 3.20 and pH 9.15. The distributions of pH values changed with each survey revealing a progressive reduction in the frequency of acid values (pH<5) and an increase in the frequency of values in the range pH 5.8 to 6.2. The frequency of values > pH 8 also increased across the surveys ***(Fig. 3.4)***.

Figure 3.4: Histograms showing distribution of soil pH (0-15 cm) measurements for a) 1978, b) 1998, c) 2007 and d) cumulative frequency. Histogram frequencies normalised to percentage of total number of samples analysed in each survey.



Approximately 42% of plots were sampled only once in the three surveys ***(Table 3.2)*** reflecting the large increase in the number of plots in sampled 2007. For plots with repeat measurements, an increase of 0.2 pH units or more was recorded for an average 66% of plots, 11% of plots showed no change and 22% showed a decrease in pH of 0.2 pH units or more ***(Table 3.3)***. This reflects the range of variability always seen in large scale surveys such as CS. Statistical significance in the categories of interest however are the critical issue.

Table 3.2: Number of plots recording a measurement of soil pH (0-15 cm) in each Countryside Survey.

	Survey years			Total number of samples
	1978	1998	2007	
1978 only	274			274
1998 only		160		160
2007 only			1719	1719
1978 &1998 only	111	111		222
1998 & 2007 only		173	173	346
1978 & 2007 only	179		179	358
1978 & 1998 & 2007	688	688	688	2064
Total number of plots	1252	1132	2759	5143

Table 3.3: Percentage of samples from repeat plots in each Countryside Survey showing a decrease in pH of 0.2 units or more (ΔpH-ve), no change in pH (ΔpH 0) or an increase in pH of 0.2 units or more (ΔpH +ve).

	No. of sites %		
	ΔpH -ve	ΔpH 0	ΔpH +ve
1978-1998	27	9	64
1998-2007	23	14	63
1978-2007	19	9	72
Mean	23	11	66

3.3.2 Change in mean soil pH (0-15 cm) across Great Britain

The state and change in soil pH across Great Britain over the three Countryside Surveys is summarised in ***Table 3.4***. Soils beneath Broad Habitats in Great Britain covered a wide range of pH; the most acid soils comprised those beneath Coniferous Woodland, Bog and Dwarf Shrub Heath Broad Habitats where mean pH in 2007 was ≈ 4.5, whilst the least acid soils (0-15 cm) were those in the enclosed farmland Broad Habitats with mean pH values ranging between 6.3 and 7.2 in 2007.

With the exception of Coniferous Woodlands, mean soil pH (0-15 cm) increased significantly in all Broad Habitats over the 29 years from the first survey in 1978. Mean soil pH beneath Coniferous Woodland remained unchanged over the 29 year period whilst beneath Bracken Broad Habitat, the only significant increase in mean pH was between 1978 and 2007. No significant increases in mean pH were observed amongst the more acid (1978 mean pH < 5) and organic-rich Broad Habitats between 1998 and 2007. In contrast mean soil pH increased between each Countryside Survey in those Broad Habitats with a 1978 mean pH >5.

Analysis of the data in relation to AVC broadly reflected the results by Broad Habitat. In the less acid AVCs (Fertile and Infertile Grassland and Crops and Weeds, mean pH 2007 > 6) there was a significant increase in mean soil pH between all three surveys. For those AVCs with a mean pH in 2007 of 5 or less, there was no significant change in mean soil pH between 1998 and 2007, but a significant increase was observed between 1978 and 1998 which largely accounted for the increase between 1978 and 2007. There were no significant changes in mean soil pH in the Tall Grass and Herb AVC and in Lowland Woodlands the only significant soil pH increase occurred between 1978 and 2007.

Table 3.4: Changes in mean soil pH (0-15 cm) across Great Britain for a) Broad Habitats, b) Aggregate Vegetation Classes (AVC) c) AVCs unchanged since 1978 and d) LOI categories. Arrows denote a significant change ($p<0.05$) in the direction shown. Diagonal line indicates too few samples to provide reliable value.

a) Great Britain - Broad Habitat

	Mean pH			Direction of significant changes		
Broad Habitat	1978	1998	2007	1978-1998	1998-2007	1978-2007
Broadleaved, Mixed and Yew Woodland	5.09	5.47	5.75	↑	↑	↑
Coniferous Woodland	4.32	4.39	4.50			
Arable and Horticulture	6.59	6.81	7.20	↑	↑	↑
Improved Grassland	5.79	6.06	6.27	↑	↑	↑
Neutral Grassland	5.52	5.99	6.14	↑	↑	↑
Acid Grassland	4.44	4.72	4.78	↑		↑
Bracken	4.14	4.47	4.64			↑
Dwarf Shrub Heath	4.19	4.50	4.55	↑		↑
Fen, Marsh and Swamp	4.64	5.35	5.45	↑		↑
Bog	4.29	4.49	4.51	↑		↑
All habitat types	5.39	5.67	5.87	↑	↑	↑

b) Great Britain - AVC whole dataset

	Mean pH			Direction of significant changes		
Aggregate Vegetation Class	1978	1998	2007	1978-1998	1998-2007	1978-2007
All Woodland	4.52	4.87	5.01	↑		↑
Upland Woodland	4.17	4.53	4.59	↑		↑
Lowland Woodland	5.06	5.31	5.66			↑
Fertile Grassland	6.05	6.23	6.45	↑	↑	↑
Infertile Grassland	5.49	5.86	6.10	↑	↑	↑
Moorland Grass Mosaic	4.40	4.77	4.77	↑		↑
Heath and Bog	4.26	4.42	4.44	↑		↑
Tall Grass and Herb	6.45	6.85	6.89			
Crops and Weeds	6.57	6.79	7.25	↑	↑	↑

c) Great Britain - AVC unchanged

	Mean pH			Direction of significant changes		
Aggregate Vegetation Class	1978	1998	2007	1978-1998	1998-2007	1978-2007
All Woodlands	4.21	4.54	4.82	↑		↑
Upland Woodland	/	/	/	/	/	/
Lowland Woodland	/	/	/	/	/	/
Fertile Grassland	6.00	6.08	6.43		↑	↑
Infertile Grassland	5.49	5.81	6.19	↑	↑	↑
Moorland Grass Mosaic	4.39	4.76	4.78	↑		↑
Heath and Bog	4.35	4.57	4.57	↑		↑
Tall Grass and Herb	/	/	/	/	/	/
Crops and Weeds	7.01	6.94	7.38		↑	↑

d) Great Britain - Loss on ignition category

	Mean pH			Direction of significant changes		
LOI category (%)	1978	1998	2007	1978-1998	1998-2007	1978-2007
Mineral (0-8)	6.19	6.43	6.74	↑	↑	↑
Humus-mineral (8-30)	5.30	5.67	5.90	↑	↑	↑
Organo-mineral (30-60)	4.58	4.95	4.96	↑		↑
Organic (60-100)	4.25	4.45	4.44	↑		↑

In order to remove the effects of vegetation / land use change, statistical analysis was performed on a subset of the plots which had been sampled in all three Surveys and for which the AVC had remained unchanged over time. AVC is only recorded at the time of each Countryside Survey so change in the intervening years cannot be ruled out, but the plots for which AVC has not changed will have a vegetation composition that has remained largely consistent in 1978, 1998 and 2007.

Restricting the analysis to plots where AVC has remained unchanged since 1978 resulted in three Classes having insufficient data for analysis (Upland and Lowland Woodland and Tall Grass and Herb). Amongst the remaining unchanged AVCs, the only differences in the results were for Fertile Grassland and Crops and Weeds where the significant increase in mean soil pH between 1978 and 1998 was lost. For Fertile Grassland, the mean soil pH values recorded for the whole dataset and for the AVC unchanged data were very similar, suggesting that significance was lost due to a reduction in the number of samples. In contrast, for Crops and Weeds, the 1978 mean values differ by 0.44 units between the two datasets suggesting that restricting the analysis to unchanged plots has eliminated some that were either mis-classified in 1978 or were responding to changes in landuse / vegetation prior to 1978.

In all three surveys, the most acid soils corresponded to those with the highest organic matter content ***(Table 3.4)*** reflecting the broad inverse relationship between soil pH and LOI ***(Fig. 3.5)***. The lower boundary pH values to this relationship decreased approximately linearly from pH 4 to pH 3.4 across the full range of LOI values. The upper boundary value decreased more steeply from pH 9.15 at less than 1% LOI to pH 4.96 at 96% LOI. Mineral soils therefore had a much wider pH range (e.g. pH 3.94 to 8.6 at 4% LOI) compared with organic soils (e.g. pH 3.5 to 5.1 at 95% LOI). Due to the logarithmic pH scale, the range in hydrogen ion concentrations was actually greater in organic soils (equivalent to 771 μEq / kg at 95% LOI) compared to mineral soils (equivalent to 287 μEq /kg at 4% LOI).

Mean soil pH increased significantly across all three Countryside Surveys in mineral soils with an LOI less than 30% ***(Table 3.4)***. There was no significant change in mean soil pH for organo-mineral and organic soils between 1998 and 2007, although there was a significant increase in mean pH between 1978 and 1998 which largely accounted for the significant increase between 1978 and 2007 ***(Fig. 3.6)***.

Figure 3.5: The relationship between soil pH (0-15 cm) and Loss on Ignition in 2007.

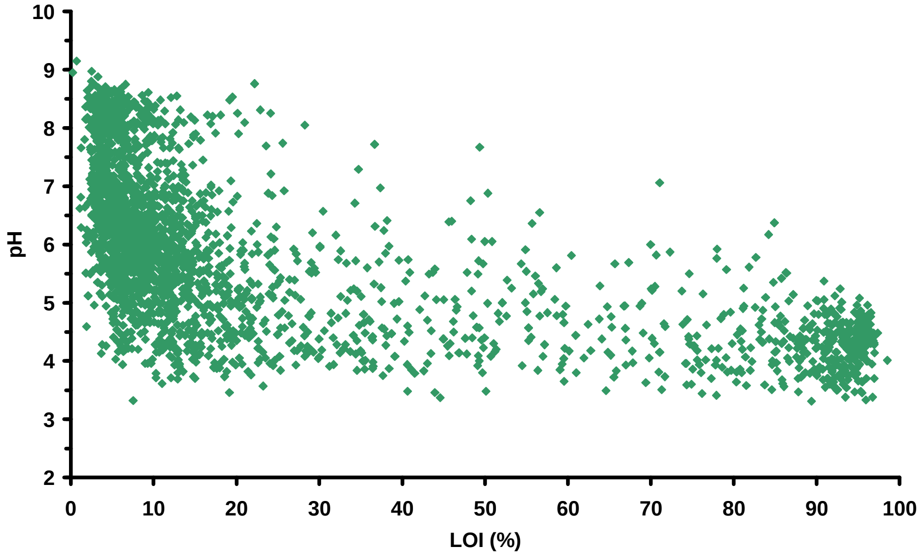
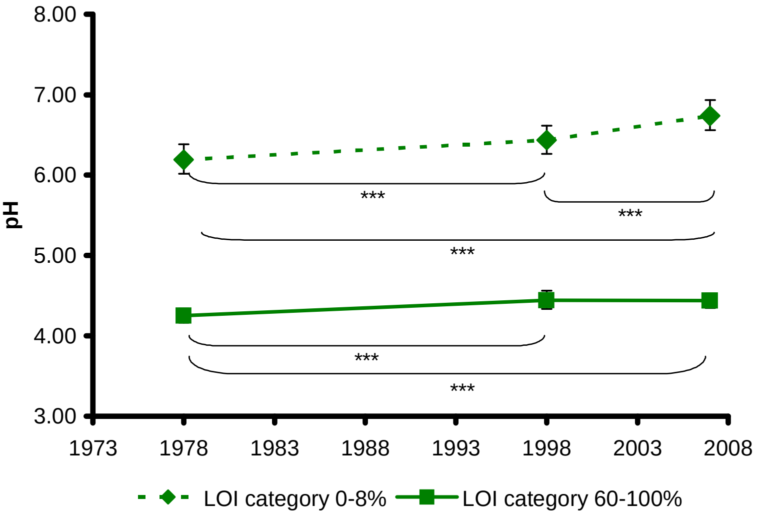


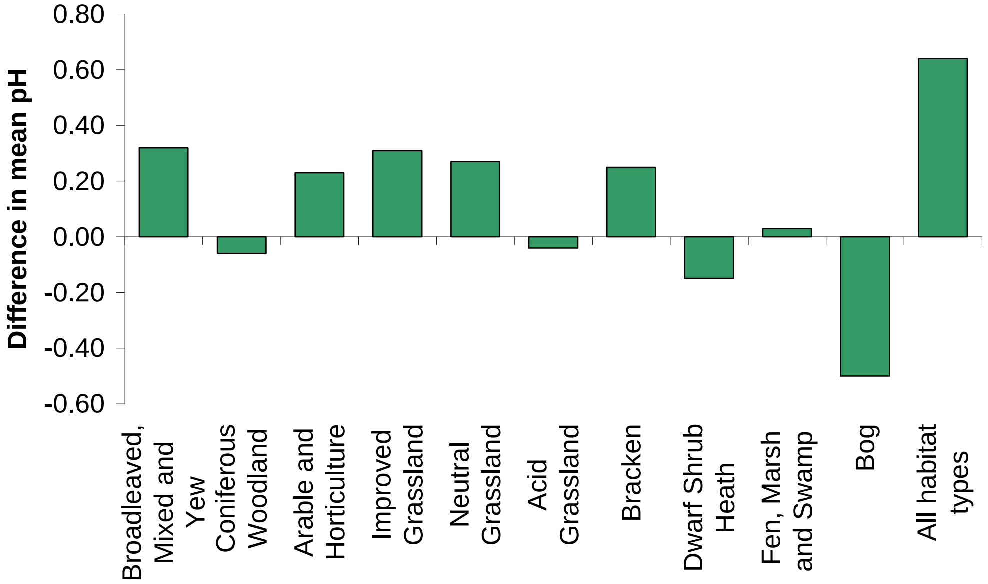
Figure 3.6: The change in the mean pH of soils (0-15 cm) for mineral soils (0-8% LOI) and organic soils (60-100% LOI) between 1978 and 2007. Significant changes (* p<0.001) are show between the dates bracketed. 95% CI are shown for each data point.**



3.3.3 Change in mean soil pH (0-15 cm) across England

Mean soil pH (0-15 cm) values in the All Broad Habitats category for England were approximately 0.5 pH units higher compared to Great Britain as a whole ***(Fig. 3.7)***, with significant increases observed between each survey and over the 29 year period since 1978 (***Table 3.5 and Fig. 3.8***).

Figure 3.7: Differences between England and Great Britain in mean soil pH (0-15 cm) for all Broad Habitats.



Soils beneath enclosed farmland Broad Habitats were the least acid in England, with mean pH values > 6.5 in 2007 and significant increases in mean soil pH between each survey. Mean soil pH (0-15 cm) in English enclosed farmland was ≈ 0.25 pH units higher than for Great Britain as a whole ***(Fig. 3.7)***. In contrast to Great Britain, Bog soils were the most acid in England (2007 mean pH 4.01) and no significant changes in mean pH were recorded across the 29 year period of Countryside Survey. Apart from Bog, Fen, Marsh and Swamp and Coniferous Woodland, all other Broad Habitats showed a significant increase in mean soil pH between 1978 and 2007. In contrast to Great Britain as whole, mean soil pH in Bracken and Dwarf Shrub Heath Broad Habitats increased significantly between 1998 and 2007, but not between 1978 and 1998; the mean pH of Acid Grassland soils increased significantly between all three surveys.

With the exception of Heath and Bog AVC, where no significant changes were observed, and Crops and Weeds where there were too few samples for statistical analysis, the mean soil pH (0-15 cm) increased significantly in all AVCs between 1978 and 2007 in England ***(Table 3.5)***. This broadly reflects the results for analysis by Broad Habitat, except that soil pH increased significantly in the Upland Woodland AVC but not in Coniferous Forest Broad Habitat possibly due to the inclusion of some broadleaf woodland within the Upland Woodland AVC and exclusion of lowland coniferous woodland. Mean soil pH increased significantly between 1998 and 2007 in Moorland Grass Mosaic in England in contrast to Great Britain where no significant change was recorded over this period. Restricting statistical analysis to unchanged AVCs eliminated several classes due to small sample numbers. Significance was lost for the change in mean soil pH between 1978 and 1998 for Infertile Grassland and Crops and Weeds. This may be due to a reduction in sample numbers but for Crops and Weeds, the mean soil pH for the unchanged dataset (pH 7.09) was approximately 0.3 pH units higher than for the whole dataset. Restricting the analysis to unchanged plots may have eliminated some plots that were either mis-classified in 1978 or responding to changes in landuse / vegetation prior to 1978.

For England, the most organic-rich (60-100% LOI category, ***Table 3.5***) soils were not represented in sufficient numbers for statistical analysis. Mean soil pH (0-15 cm) was highest in the mineral category (2007 pH 7.02) and lowest in the organo-mineral soils (2007 pH 5.02). Mean soil pH increased significantly between each Survey and across the 29 years since 1978 in soils with less than 30% LOI. For organo-mineral soils (30-60% LOI), mean soil pH increased significantly between 1978 and 1998 which largely accounted for the significant increase between 1978 and 2007. These results were consistent with those for Great Britain as a whole.

Figure 3.8: The change in the mean pH of soils (0-15 cm) for across all Broad Habitats in England and Great Britain between 1978 and 2007. Significant changes (* p<0.001) are show between the dates bracketed. 95% CI are shown for each data point.**

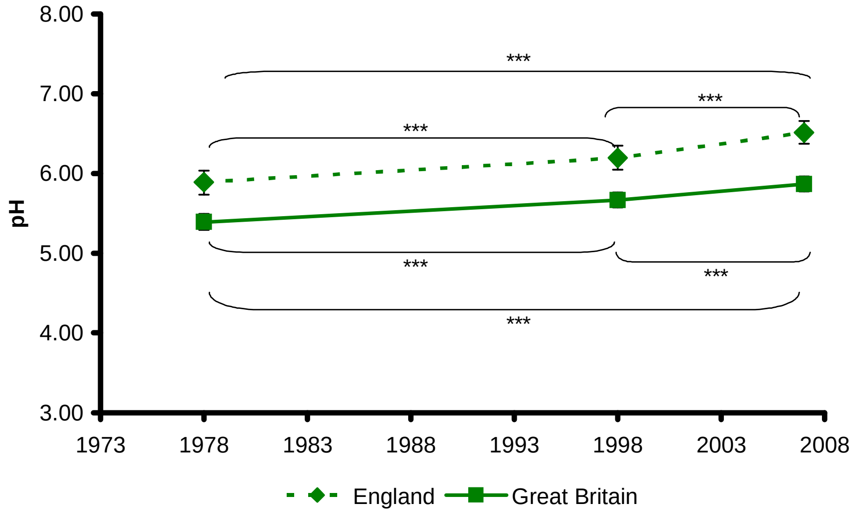


Table 3.5: Changes in mean soil pH (0-15 cm) across England for a) Broad Habitats, b) Aggregate Vegetation Classes (AVC) c) AVCs unchanged since 1978 and d) LOI categories. Arrows denote a significant change (p<0.05) in the direction shown. Diagonal line indicates too few samples to provide reliable value.

a) England - Broad Habitat						
	Mean pH			Direction of significant changes		
Broad Habitat	1978	1998	2007	1978-1998	1998-2007	1978-2007
Broadleaved, Mixed and Yew Woodland	5.23	5.83	6.07	↑		↑
Coniferous Woodland	4.31	4.13	4.44			
Arable and Horticulture	6.71	7.02	7.43	↑	↑	↑
Improved Grassland	6.14	6.29	6.58	↑	↑	↑
Neutral Grassland	5.72	6.18	6.41	↑	↑	↑
Acid Grassland	4.04	4.51	4.74	↑	↑	↑
Bracken	4.11	4.08	4.89		↑	↑
Dwarf Shrub Heath	4.00	4.12	4.40		↑	↑
Fen, Marsh and Swamp	5.15	5.83	5.48			
Bog	4.09	4.09	4.01			
All habitat types	5.89	6.19	6.51	↑	↑	↑

b) England - AVC whole dataset

	Mean pH			Direction of significant changes		
Aggregate Vegetation Class	1978	1998	2007	1978-1998	1998-2007	1978-2007
Upland Woodland	4.01	4.34	4.57	↑		↑
Lowland woodland	5.18	5.39	5.72			↑
Fertile grassland	6.24	6.40	6.72		↑	↑
Infertile grassland	5.75	6.10	6.30	↑	↑	↑
Moorland grass mosaics	4.05	4.38	4.65	↑	↑	↑
Heath and Bog	3.98	4.16	4.24			
Tall grass and Herb	/	7.00	7.06	/		/
Crops and weeds	6.72	7.03	7.50	↑	↑	↑

c) England - AVC unchanged

	Mean pH			Direction of significant changes		
Aggregate Vegetation Class	1978	1998	2007	1978-1998	1998-2007	1978-2007
Upland Woodland	/	/	/	/	/	/
Lowland woodland	/	/	/	/	/	/
Fertile grassland	6.19	6.28	6.66		↑	↑
Infertile grassland	5.82	6.09	6.37		↑	↑
Moorland grass mosaic	/	/	/	/	/	/
Heath and Bog	/	/	/	/	/	/
Tall grass and Herb	/	/	/	/	/	/
Crops and weeds	7.09	7.05	7.53		↑	↑

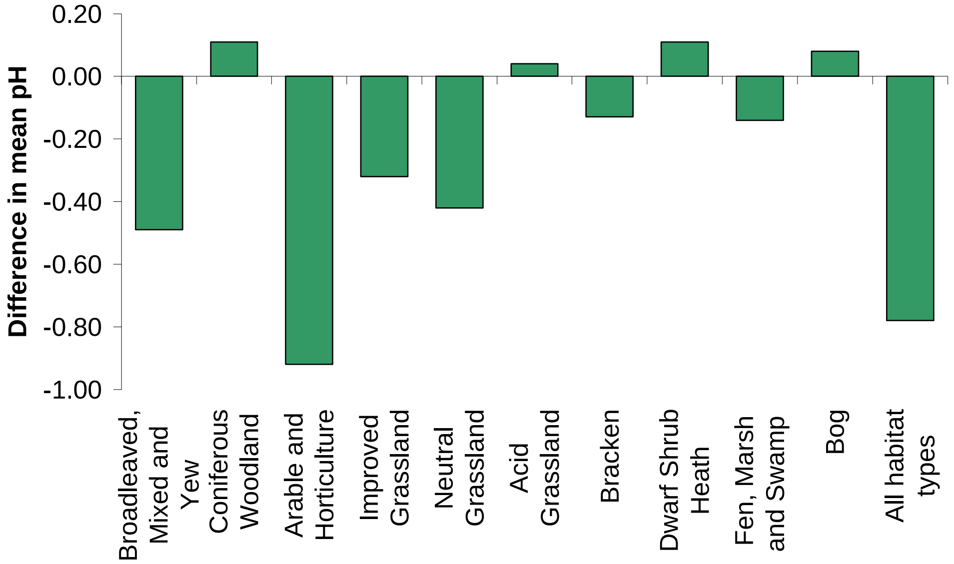
d) England - Loss on ignition category

	Mean pH			Direction of significant changes		
LOI category (%)	1978	1998	2007	1978-1998	1998-2007	1978-2007
Mineral (0-8)	6.40	6.70	7.02	↑	↑	↑
Humus-mineral (8-30)	5.73	6.01	6.40	↑	↑	↑
Organo-mineral (30-60)	4.49	5.04	5.02	↑		↑
Organic (60-100)	/	/	/	/	/	/

3.3.4 Change in mean soil pH (0-15 cm) across Scotland

There was a significant increase in mean soil pH in the All Broad Habitats category for Scotland from 1998 to 2007 ***(Table 3.6)***. Earlier increases in pH between 1978 and 1998 and overall from 1978 to 2007 were also significant ***(Table 3.5).*** Overall, mean soil pH was more acid in Scotland compared to Great Britain as a whole, most notably for the enclosed farmland Broad Habitats and for Broadleaved Woodland and Neutral Grassland ***(Fig. 3.9)***.

Figure 3.9: Differences between Scotland and Great Britain in mean soil pH (0-15 cm) for all Broad Habitats.



Soils beneath the Arable Broad Habitat were the least acidic in Scotland (2007 mean pH 6.28) and this was the only Broad Habitat to record a significant increase in mean soil pH between 1998 (pH 5.98) and 2007 (pH 6.28). Mean soil pH in the Arable Broad Habitat did not increase significantly between 1978 and 1998 or across the entire period from 1978 to 2007.

There was no significant change in mean soil pH beneath woodland Broad Habitats in Scotland between 1998 and 2007, or between 1978 and 1998 or between 1978 and 2007. There was a significant increase in soil pH between 1978 and 1998 for Improved Grassland, Neutral Grassland, Dwarf Shrub Heath, Fen Marsh and Swamp and Bog Broad Habitats which largely accounted for the significant increase in mean soil pH over the entire period from 1978 to 2007 in these Broad Habitats. Mean soil pH beneath Acid Grassland increased significanly between 1978 (pH 4.61) and 2007 (pH 4.82) but not between 1978 and 1998 or between 1998 and 2007. Bracken was the most acidic Broad Habitat in Scotland in 2007 (mean pH 4.51) but there were no significant changes in mean soil pH between any of the Surveys or over the 29 year period from 1978.

Infertile Grassland and Crops and Weeds were the only AVCs in Scotland to record a significant increase in mean soil pH between 1997 and 2007. For Infertile Grassland, this continued the trend of significant mean soil pH increase between 1978 and 1998 and across the entire period from 1978 to 2007. No other significant changes in mean soil pH were observed for Crops and Weeds. There was a significant increase in mean soil pH for Moorland Mosaics and Heath and Bog between 1978 and 1998 which largely accounted for the significant increases between 1978 and 2007. For Upland Woodland there was a significant increase in mean soil pH between 1978 and 2007, but no other significant changes were observed.

Restricting the statistical analysis to unchanged AVCs eliminated all but three classes due to small sample numbers. The only difference in the results for the remaining AVCs was the loss of significance for the increase in mean soil pH in Infertile Grassland between 1978 and 1998. The mean pH values for 1978 and 1998 and the differences between 1978 and 1998 are similar for the unchanged and the whole Infertile Grassland dataset, indicating that a reduction in sample numbers may have caused the loss of significance.

Table 3.6: Changes in mean soil pH (0-15 cm) across Scotland for a) Broad Habitats, b) Aggregate Vegetation Classes (AVC) c) AVCs unchanged since 1978 and d) LOI categories. Arrows denote a significant change ($p<0.05$) in the direction shown. Diagonal line indicates too few samples to provide reliable value.

a) Scotland - Broad Habitat

	Mean pH			Direction of significant changes		
Broad Habitat	1978	1998	2007	1978-1998	1998-2007	1978-2007
Broadleaved, Mixed and Yew Woodland	5.00	4.85	5.26			
Coniferous Woodland	4.42	4.52	4.61			
Arable and Horticulture	6.14	5.98	6.28		↑	
Improved Grassland	5.44	5.84	5.95	↑		↑
Neutral Grassland	5.31	5.71	5.72	↑		↑
Acid Grassland	4.61	4.83	4.82			↑
Bracken	4.42	4.81	4.51			
Dwarf Shrub Heath	4.31	4.63	4.66	↑		↑
Fen, Marsh and Swamp	4.59	5.24	5.31	↑		↑
Bog	4.34	4.53	4.59	↑		↑
All habitat types	4.81	5.02	5.09	↑	↑	↑

b) Scotland - AVC whole dataset

	Mean pH			Direction of significant changes		
Aggregate Vegetation Class	1978	1998	2007	1978-1998	1998-2007	1978-2007
Upland Woodland	4.32	4.64	4.70			↑
Lowland woodland	/	/	/	/	/	/
Fertile grassland	5.75	5.94	6.08			↑
Infertile grassland	5.35	5.67	5.89	↑	↑	↑
Moorland grass mosaics	4.51	4.90	4.87	↑		↑
Heath and Bog	4.34	4.50	4.53	↑		↑
Tall grass and Herb	/	/	/	/	/	/
Crops and weeds	6.07	5.78	6.16		↑	

c) Scotland - AVC unchanged

	Mean pH			Direction of significant changes		
Aggregate Vegetation Class	1978	1998	2007	1978-1998	1998-2007	1978-2007
Upland Woodland	/	/	/	/	/	/
Lowland woodland	/	/	/	/	/	/
Fertile grassland	/	/	/	/	/	/
Infertile grassland	5.25	5.54	5.93		↑	↑
Moorland grass mosaic	4.51	4.86	4.89	↑		↑
Heath and Bog	4.40	4.61	4.61	↑		↑
Tall grass and Herb	/	/	/	/	/	/
Crops and weeds	/	/	/	/	/	/

d) Scotland - Loss on ignition category

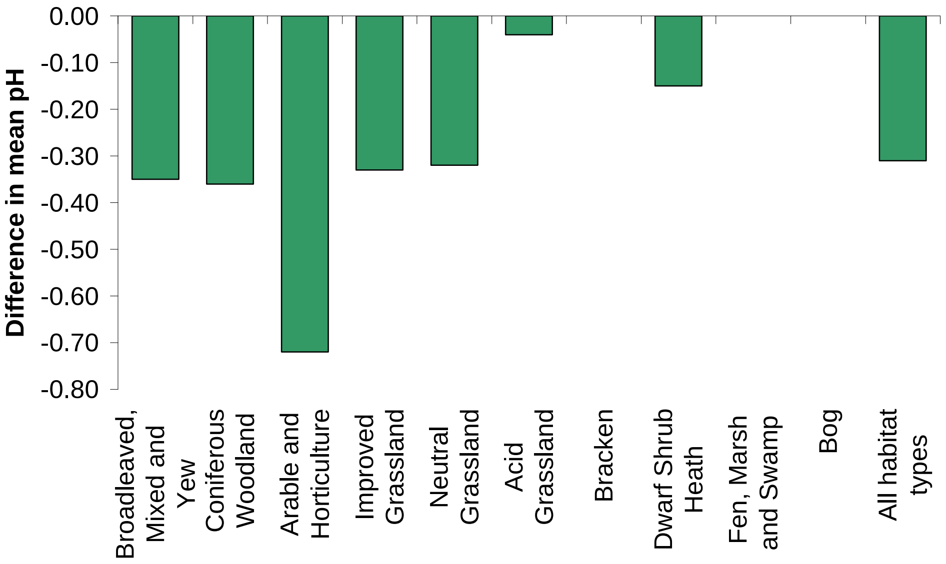
	Mean pH			Direction of significant changes		
LOI category (%)	1978	1998	2007	1978-1998	1998-2007	1978-2007
Mineral (0-8)	5.75	5.82	6.05		↑	↑
Humus-mineral (8-30)	4.96	5.35	5.45	↑		↑
Organo-mineral (30-60)	4.64	4.87	4.96			↑
Organic (60-100)	4.30	4.51	4.50	↑		↑

In 2007 the mean soil pH in mineral and humus-mineral soils in Scotland was approximately 0.5 pH units lower compared to the equivalent soils across Great Britain as a whole ***(Tables 3.4*** and ***3.6)***. In contrast, the mean soil pH of the organic-rich soils (> 30% LOI) was approximately the same in Scotland and across Great Britain in 2007. For soils in all LOI categories there was a significant increase in mean pH between 1978 and 2007, but the patterns of change with respect to LOI category for other periods were much less consistent in Scotland compared to Great Britain as a whole. Mineral soils were the only category to record a significant increase in mean soil pH between 1998 and 2007. The mean pH of humus-mineral and organic soils increased significantly between 1978 and 1998 which largely accounted for the increase in mean soil pH between 1978 and 2007. For organo-mineral soils (30-60% LOI), there were no significant changes in mean soil pH between 1978 and 1998 or between 1998 and 2007.

3.3.5 Change in mean soil pH (0-15 cm) across Wales

The most acid soils in Wales in 2007 were those beneath Coniferous Woodland (pH 4.14), whilst soils beneath enclosed farmland Broad Habitats were the least acid ***(Table 3.7)***. There were no significant changes in mean soil pH for any of the Broad Habitats in Wales between 1998 and 2007. The mean pH of soils beneath Broadleaved Woodland, Improved Grassland and Neutral Grassland increased significantly between 1978 and 1998 and this accounted for much of the significant increase in mean soil pH between 1978 and 2007 in these Broad Habitats. For Coniferous Woodland, Acid Grassland and Dwarf Shrub Heath, there were no significant changes in mean soil pH between any of the Surveys or across the entire period between 1978 and 2007. Mean soil pH was more acid in Wales for all Broad Habitats relative to mean values for Great Britain ***(Fig. 3.10)***.

Figure 3.10: Differences between Wales and Great Britain in mean soil pH (0-15 cm) for all Broad Habitats.



Infertile Grassland and Fertile Grassland were the only AVCs to have sufficient data to report state and change for all three Countryside Surveys ***(Table 3.7)***. The mean pH of soils beneath Fertile Grassland did not change significantly between any of the Surveys or across the period from 1978 to 2007. For Infertile Grassland, there was a significant increase in mean soil pH between 1998 and 2007, between 1978 and 1998 and across the entire period from 1978 to 2007. Restricting the statistical analysis to unchanged AVCs eliminated all but Infertile Grassland which showed very similar results to the AVC dataset as a whole. It is unlikely therefore, that the changes observed in mean soil pH for Infertile Grassland in Wales resulted from a change in land use or vegetation composition.

There was no significant change in the mean soil pH of mineral or humus-mineral soils in Wales between 1998 and 2007 and there were too few data to report on state and change in mean soil pH for organo-mineral and organic soils ***(Table 3.7)***. The mean pH of mineral soils (0-15 cm) did not change significantly between any of the surveys or across the entire period from 1978 to 2007. There was a significant increase in the mean pH of humus mineral soils (0-15 cm) between 1978 and 1998 and this largely accounted for the significant increase in mean soil pH between 1978 and 2007.

Table 3.7: Changes in mean soil pH (0-15 cm) across Wales for a) Broad Habitats, b) Aggregate Vegetation Classes (AVC) c) AVCs unchanged since 1978 and d) LOI categories. Arrows denote a significant change ($p<0.05$) in the direction shown. Diagonal line indicates too few samples to provide reliable value.

a) Wales - Broad Habitat

	Mean pH			Direction of significant changes		
Broad Habitat	1978	1998	2007	1978-1998	1998-2007	1978-2007
Broadleaved, Mixed and Yew Woodland	4.53	5.24	5.40	↑		↑
Coniferous Woodland	3.73	4.22	4.14			
Arable and Horticulture	5.00	/	6.48	/	/	
Improved Grassland	5.36	5.74	5.94	↑		↑
Neutral Grassland	5.06	5.85	5.82	↑		↑
Acid Grassland	4.34	4.41	4.74			
Bracken	/	/	/	/	/	/
Dwarf Shrub Heath	4.13	4.53	4.40			
Fen, Marsh and Swamp	/	/	/	/	/	/
Bog	/	/	/	/	/	/
All habitat types	5.00	5.43	5.56	↑		↑

b) Wales - AVC whole dataset

	Mean pH			Direction of significant changes		
Aggregate Vegetation Class	1978	1998	2007	1978-1998	1998-2007	1978-2007
Upland Woodland	/	/	4.41	/	/	/
Lowland woodland	/	/	/	/	/	/
Fertile grassland	5.85	6.08	6.08			
Infertile grassland	5.07	5.54	5.90	↑	↑	↑
Moorland grass mosaics	/	/	4.64	/	/	/
Heath and Bog	/	/	4.29	/	/	/
Tall grass and Herb	/	/	/	/	/	/
Crops and weeds	/	/	/	/	/	/

c) Wales - AVC unchanged

	Mean pH			Direction of significant changes		
Aggregate Vegetation Class	1978	1998	2007	1978-1998	1998-2007	1978-2007
Upland Woodland	/	/	/	/	/	/
Lowland woodland	/	/	/	/	/	/
Fertile grassland	/	/	/	/	/	/
Infertile grassland	5.05	5.50	6.09	↑	↑	↑
Moorland grass mosaic	/	/	/	/	/	/
Heath and Bog	/	/	/	/	/	/
Tall grass and Herb	/	/	/	/	/	/
Crops and weeds	/	/	/	/	/	/

d) Wales - Loss on ignition category

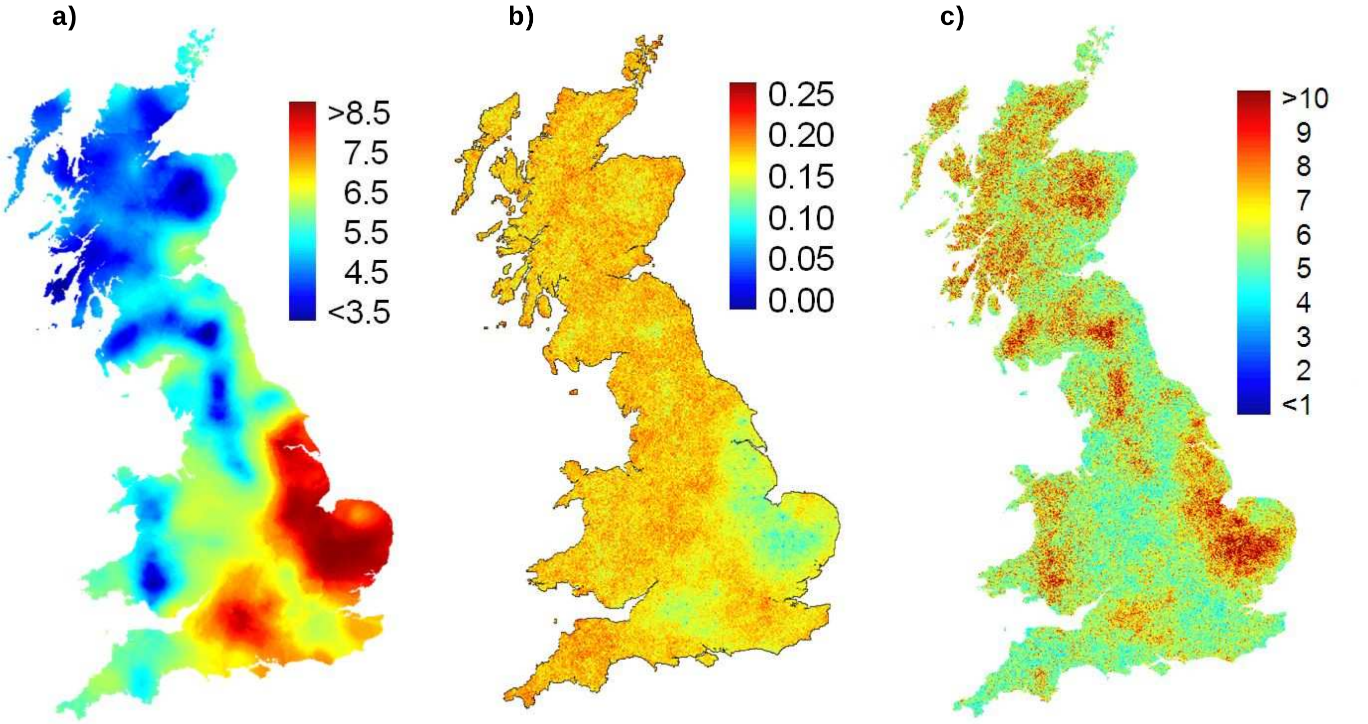
	Mean pH			Direction of significant changes		
LOI category (%)	1978	1998	2007	1978-1998	1998-2007	1978-2007
Mineral (0-8)	5.54	5.88	6.13			
Humus-mineral (8-30)	4.87	5.47	5.55	↑		↑
Organo-mineral (30-60)	/	/	/	/	/	/
Organic (60-100)	/	/	/	/	/	/

3.4 Discussion and Policy Implications

Soils (0-15 cm) in Great Britain and regionally within individual countries covered a wide range of pH in 2007 from a minimum of pH 3.2 to a maximum of pH 9.15. Organic soils were consistently the most acid, whilst the highest pH values were encountered in mineral soils which also showed the widest range in soil pH. The least acidic soils with a mean pH in excess of 6 were generally found in moderate to intensively managed agricultural land such as Arable and Improved Grassland Broad Habitats and Fertile Grassland and Crops and Weeds AVCs. Acidic soils with a mean pH less than 5 were associated with Coniferous Woodland, Acid Grassland, Dwarf Shrub Heath and Bog Broad Habitats and the Upland Woodland, Moorland Grass Mosaic and Heath and Bog AVCs. These generally had organic-rich soils whereas managed agricultural land was associated with soils with a low organic matter content ***(Chapter 2)***.

The mapped distribution of soil pH in 2007 ***(Fig. 3.11)*** followed the anticipated pattern, with lower pH soils in the upland areas of Wales, Pennines and much of Scotland. The coefficient of variation (CV, standard deviation / mean, an indicator of the spread of the data around the mean value) was lowest in areas dominated by either high pH soils which are intensively managed or low pH soils in upland areas where there is little variation. Conversely, the signal to noise ratio (SNR, mean / standard deviation) indicated that for values above 1 the signal was stronger than the noise. High SNRs were observed across managed arable areas in eastern England and agricultural land in southern central England. This may occur because soil management leads to greater uniformity of pH values across these areas. High SNRs in the uplands reflect the presence of acidic peaty and peaty mineral soils in Acid Grassland, Dwarf Shrub Heath, Bog and Coniferous Woodland Broad Habitats. For England and Wales, the broad patterns in the soil pH data ***(Fig. 3.11)*** correspond well to maps originating from the National Soil Inventory dataset (NSI; McGrath and Loveland, 1992) and the Representative Soil Sampling Scheme (RSSS; Baxter *et al.*, 2006) although the latter are restricted to managed agricultural land.

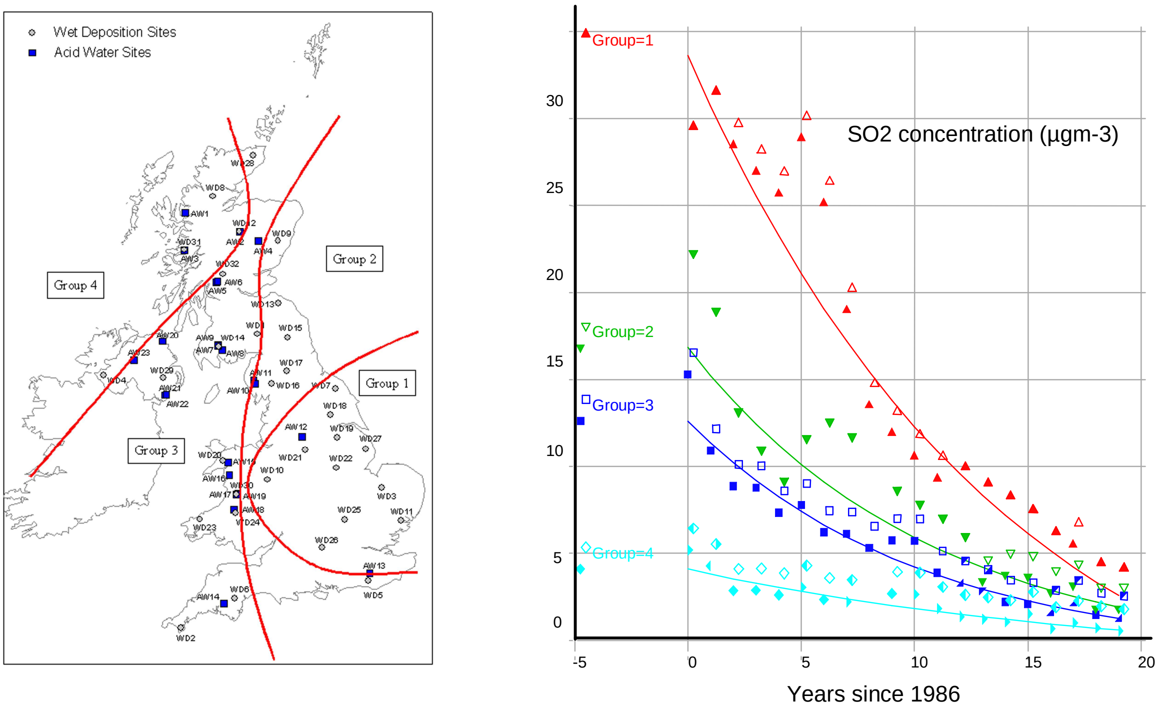
Figure 3.11: **Maps of soil (0-15 cm) pH in 2007 (a) using ordinary Kriging (pH units), (b) coefficient of variation and (c) signal to noise ratio.**



Across Great Britain and regionally within the individual countries, soils (0-15 cm) showed evidence of increasing pH (decreasing acidity) between 1978 and 2007. This is consistent with a response to a reduction in acid deposition over the last 29 years (NEGTAP, 2001; RoTAP, 2010). For the more organic-rich soils and their associated Broad Habitats and AVCs, the significant increase in mean pH between 1978 and 2007 was largely accounted for by the increase between 1978 and 1998. Generally there was no significant pH change recorded between 1998 and 2007 for organic-rich soils (>30% LOI). In contrast for mineral and humus-mineral soils and associated Broad Habitats and AVCs, significant increases in soil pH were often observed between each Survey as well as across the entire period from 1978 to 2007. This was a consistent pattern for plots with unchanged AVC classification in the different surveys indicating land use change was not responsible for the trends observed. However, land management within squares such as changes in rates of lime and fertiliser applications or stocking densities may play an important role which is currently being investigated.

When comparing changes in pH between different soil types, Broad Habitats or AVCs, it must be remembered that pH is a logarithmic scale. An equal rate of recovery, in terms of pH units, would not be expected for a low pH and a high pH soil. Conversion of pH data to hydrogen ion concentrations reveals that annual rates of change in hydrogen ion concentration for high pH, low organic matter soils has been sustained across the 29 year period. The large annual rate of change between 1978 and 1998 for more organic-rich, low pH soils slowed dramatically between 1998 and 2007. The different trends observed for mineral and organic soils may indicate that the soil response to reducing mineral acid inputs from the atmosphere is influenced by soil organic matter content possibly as a result of buffering by organic acids. As the concentration of mineral acids in the soil declines and soil solution pH rises, organic acids will come into solution and de-protonate providing a buffering mechanism to further pH change. In addition, organic-rich soils are broadly located in the north and west of the British Isles where initial pollution levels were lowest and reductions in acid deposition have been smaller than anticipated given the size of the emission reductions and less than in regions such as central England which are closer to the main emission sources (***Fig. 3.12***; NEGTAP, 2001; RoTAP 2010).

Figure 3.12: a) The regional grouping of sites in the UK precipitation chemistry network used in the statistical analysis of trends. B) Trends in SO2 over the last 20 years in the four groups of monitoring stations.



a)

b)

Identifying the relative influence of these factors is important to assessing the “success” of emission control policy for acid deposition and will be the subject of further analysis. Thus in semi-natural systems on the more organic-rich soils, the implications for biodiversity and metal mobilisation are not clear until further analysis determines the cause of the lack of change in soil pH. Current risk assessment tools using the critical load methodology indicate the majority of these systems remain at risk from acidic deposition and thus the lack of further increases in soil pH needs to be investigated closely (RoTAP, 2010). One possibility is the variability in initial acidic deposition inputs and subsequent trends ***(Fig. 3.12).***

The significant increase in mean soil pH between 1978 and 2007 observed for managed agricultural land will be influenced by farming practice such as moves towards deeper cultivation bringing relatively unweathered chalk parent material to the soil surface. In England, many areas of arable and arable ley or short term grassland are located in areas close to emission sources and will have experienced relatively large reductions in acid deposition loading, especially from dry deposition of SO_2 (NEGTAP, 2001) compared to areas further west where wet deposition dominates inputs.

The influence of agricultural management is difficult to separate from external factors and the evidence from other soil surveys is contradictory. The RSSS (Skinner *et al.*, 1992) is exclusively focussed on soils under agricultural management. Re-analysis of the RSSS data (Oliver *et al.*, 2006) showed that the temporal change in agricultural soil pH was small between 1971 and 2001. Spatial disaggregation of the RSSS data indicated that soil pH declined in areas of permanent grassland such as the west of England and Wales possibly because farmers did not maintain lime inputs following the loss of subsidy in 1976 (Skinner and Todd, 1998; Baxter *et al.*, 2006). The RSSS data also showed that soil pH had changed little over time in arable and arable ley systems with the interpretation that arable farmers have maintained optimal pH levels for crop production (Oliver *et al.*, 2006). Selective re-sampling of arable, arable-ley and permanent (managed) grassland sites of the National Soil Inventory showed an increase in soil pH of between 0.1 and 0.3 pH units between the early 1980s and 1995/96 (Defra, 2003). The NSI data corroborate the results from Countryside Survey for England and Wales between 1978 and 1998; mean pH values for equivalent land use types are also similar. Currently there are no other published national-scale datasets to provide evidence of pH change in agricultural soils between 1998 and 2007.

The soil pH data show an increase over time in the frequency of pH values in excess of pH 8.5. In 2007 approximately two thirds of the 54 plots with pH > 8.5 were in the Arable Broad Habitat, with values approaching pH 9 in some plots. Soil pH values in excess of 8.3 indicate that calcium carbonate solubility is no longer controlling soil pH and there is an influence from sodium salts accumulating in the soil. Two of the sample points with the highest pH values are very close to the coast and are mapped as Littoral Sediment or Supra-littoral Sediment Broad Habitats where sodium will be abundant. Several sample sites are located in the fens of East Anglia and again, there may be abundant sodium in these soils. The remaining sites are further west in Oxfordshire and may be influenced by irrigation which can lead to sodium accumulation in the soil.

Across Great Britain and within individual countries, Coniferous Woodland was consistently amongst the most acidic of the Broad Habitats and showed no significant temporal changes in mean soil pH. Whilst sample numbers were relatively low in England and Wales (c.40), Broad Habitats with fewer samples have shown significant pH increases and samples numbers in Scotland (125) and across Great Britain as a whole (207) were easily sufficient to detect change. The implication from Countryside Survey is that soils beneath Coniferous Woodlands are either responding very slowly to changes in acid deposition or other factors, such as accumulation of acidic organic matter are controlling soil pH in these systems. Large areas of conifer forest are located at relatively high altitude in the north and west of Britain where annual rainfall is high, wet deposition, enhanced by seeder-feeder effects dominates atmospheric inputs (Dore *et al.,* 1992) and forest canopies are frequently enveloped in cloud which even now can contain high concentrations of atmospheric pollutants. Given this environment and the ability of conifer canopies to efficiently scavenge air pollutants from the atmosphere (Fowler *et al.*, 1989), the positive effects of emission reductions may be attenuated in Coniferous Woodland. There is also a known interaction between forest age or maturity and atmospheric nitrogen deposition which can potentially acidify forest soils through “nitrogen saturation” (Emmett *et al.*, 2003; Emmett and Reynolds, 1996). Atmospheric nitrogen deposition has changed little over the past 29 years whilst conifer plantations have grown older as trees planted in the 1960s reach maturity. The ongoing effects of nitrogen deposition may therefore offset the benefits of lower sulphur deposition. Aside from external influences, the build up of acidic forest floor and accumulation of base cations into standing biomass, especially in those areas with a naturally “acidic” geology and soils, may also be contributing to the sustained acidity of surface soils in Coniferous Woodland. The policy consequences of these results are more likely to affect the aquatic rather than the terrestrial environment. In Wales, for example, surface water acidification in afforested headwater catchments and the persistence of acid episodes has already been identified as a significant threat to achieving compliance to the Water Framework Directive in some upland water bodies.

3.4.1 Policy implications

The increased soil pH observed for the more mineral soils is consistent with the expected benefit of continued reductions in sulphur emissions. Data analysis is ongoing to determine if other drivers of change such as nitrogen deposition or land management is slowing recovery in the organic soils where pH did not significantly increase between 1998 and 2007. Conversion from one land use to another does not seem to be an important factor. Land management may be affecting soil pH in more intensively managed agricultural land and further work is required to separate this influence from the response to reduced acid and nitrogen deposition. The implications of these findings are that current emission control policies combined with current policies to protect soil through sustainable land management practices may not currently be sufficient to promote continued recovery from acidification in organic-rich soils.

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4. Total nitrogen and C:N

Summary

- **There were small but significant decreases in mean soil (0-15 cm) total nitrogen concentration between 1998 and 2007 in many Broad Habitats and Aggregate Vegetation Classes across Great Britain and the individual countries; no reporting category recorded an increase in mean soil (0-15 cm) total nitrogen concentration.**
- **For semi-natural and woodland soils continued input of nitrogen deposition at 20-30 kgN/ha/yr for many parts of Great Britain has not caused the expected average increase of 3-4% in this basic soil property. Instead, the decreases observed combined with a trend for an increase in total carbon to nitrogen ratio suggest there may be increased nitrogen loss or uptake possibly combined with a trend for increased carbon density as reported for some soils in Chapter 2. The effects of one or both of these processes would be to effectively 'dilute' the soil (0-15cm) nitrogen concentration signal. Both processes (increased nitrogen loss and increased carbon fixation by plants leading to storage in soil) are known possible consequences of nitrogen enrichment which can result in vegetation composition change and thus this parameter may not be a sensitive indicator of eutrophication from atmospheric nitrogen deposition.**
- **There was no change or a small significant decline in mean soil total nitrogen concentrations in improved and fertile grassland categories between 1998 and 2007 across Great Britain and within individual countries despite major reductions in fertiliser use. As there is no change in the soil (0-15cm) total carbon to nitrogen ratio this indicates farmers have maintained soil nitrogen status in managed grassland systems despite a reduction in mineral fertiliser use possibly due to use of alternative organic sources of nitrogen such as slurry and organic waste products.**
- **In cropland systems, a significant decline in soil (0-15cm) total nitrogen concentrations and total carbon to nitrogen ratios was observed between 1998 and 2007 for Great Britain and England. A significant decline in soil (0-15cm) total carbon concentrations was also reported (Chapter 2). As there is only a small decline in fertiliser use in these systems and there is evidence of combined carbon and nitrogen loss, deep ploughing, erosion or increased decomposition rates may be the most likely explanation of this trend.**

4.1 Introduction

Key question: Can the trend of eutrophication of the countryside be detected in the soil as well as the vegetation using this basic soil property?

Measurements: Repeat measurement of soil (0-15 cm) total nitrogen concentration measured in all plots sampled in 1998.

Soil total nitrogen concentration (hereafter called soil N concentration) and stock are basic fundamental measurements of soil fertility. They are relatively insensitive to short-term changes, but over a longer time period give an overall indication of trends in soil fertility and changes in nutrient status in relation to other parameters such as carbon (C). Changes in plant species composition were observed following the Countryside Survey (CS) in 1998 (Haines-Young, 2000) and these were ascribed to ecosystem eutrophication following enhanced deposition of atmospheric N compounds.

In response to the key question, soil N concentration data can be used to provide:

- **National and country-level assessments of soil N concentration and change in soil N concentration since 1998**
- **Attribution of change in, and form of, soil N in response to pressures and drivers**
- **Attribution of change in plant species composition in relation to internal N status versus atmospheric N deposition**
- **Assessment of soil N in relation to changes in soil *C* status**

The deliverables for total soil (0-15 cm) N from CS in 2007 will be:

- **National and country-level assessments of status and change in soil (0-15 cm) total N concentration and stock since 1998**
- **Assessment of soil N in relation to changes in soil *C* status**

4.1.1 Rationale for measurement

The rationale for the measurement of soil total N concentration and stock is given in ***Table 4.1***. Total N has not been measured in surveys of soil quality in England and Wales apart from forest and woodland systems in the BIOSOIL and British Woodland Survey. It is a parameter within the National Soil Inventory for Scotland (NSIS) and is included in the soil measurements at Environmental Change Network sites.

Table 4.1: Total N: rationale for measurement

	Facts	Comments
History in CS	Total N measured in CS in 1998	Maintain time series. Enables stock and change
Links and compatibility to other monitoring programmes	Not measured in NSI	Total N has been measured in the NSIS (Scotland), BIOSOIL and the British Woodland Survey
Uniqueness of CS	No other known national datasets	Only integrated sample which can be linked to vegetation and land management
Value for money (Policy priority or interpretative value x cost)	High	High policy and interpretative value, low cost

4.2 Methods

The soil used for total N analysis was taken from the ‘Black core’ and there were no specific sampling requirements beyond those normally employed for collecting these samples (See Emmett *et al.*, 2008, Annex 1).

One thousand and twenty four samples were analysed at CEH Lancaster for total N in 2007 using the UKAS accredited method SOP3102. Samples were analysed using an Elementar Vario-EL elemental analyser (Elementaranalysensysteme GmbH, Hanau, Germany). The Vario EL is a fully automated analytical instrument working on the principle of oxidative combustion followed by thermal conductivity detection. Following combustion in the presence of excess oxygen the oxides of N and C flow through a reduction column which removes excess oxygen. C is trapped on a column whilst N is carried to a detector. C is then released from the trap and detected separately. Sample weights are usually 15 mg for peat and 15-60 mg for mineral soil samples.

The concentration of total N is expressed in % dry weight of soil, which is abbreviated in the text to %N. To calculate topsoil total N density, a measurement of N content per unit volume is needed. Combining bulk density measurements reported in ***Chapter 1*** for the 2007 samples with soil N concentration values result in estimates of topsoil (0-15 cm) N density on an area basis expressed in units of t/ha.

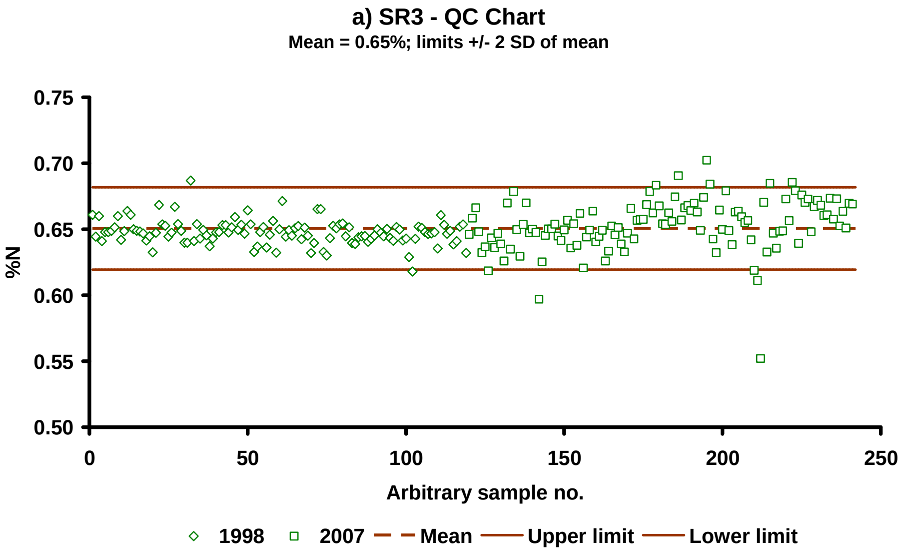
4.2.1 Quality Assurance and Quality Control

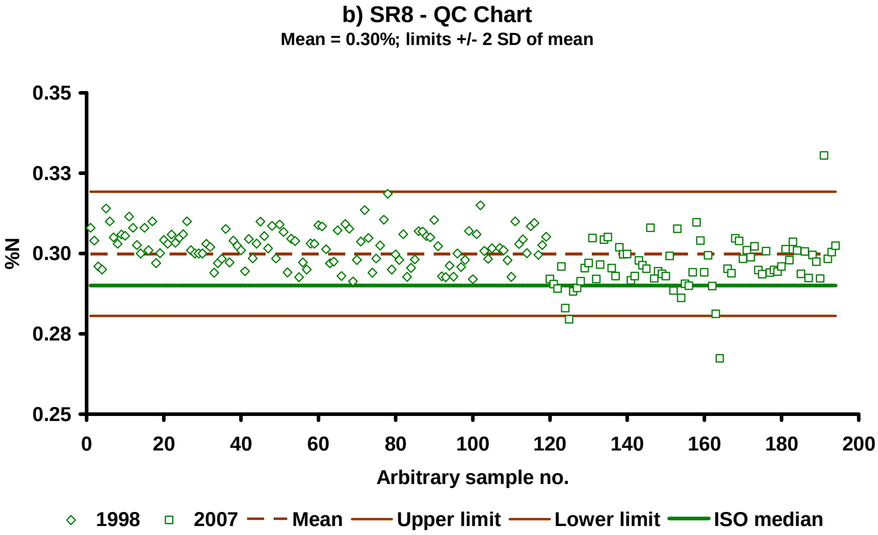
The Defra/NERC/BBSRC Joint Codes of Practice were followed.

Due to the fully automated nature of the instrument, calibration was performed infrequently, with daily runs being factorised to the instrument calibration through the use of a certified standard (acetanilide). Quality control was achieved by using two in-house reference materials analysed with each batch of samples and by the analysis of duplicate samples.

Results of the analysis of standard reference materials (SRM) SR3 and SR8 which cover a range of soil N concentration values are shown using Shewhart charts ***(Fig. 4.1a and Fig. 4.1b)***. The same standards were used in the sample batches from 1998 and 2007 and the relative performance of the analysis can be compared.

Figure 4.1: Shewhart QC charts for total N analysis (%) of standard reference materials a) SR3 and b) SR8.





The Quality Control charts provide evidence of acceptable results for the analyses undertaken in 1998 for both SRMs. More points fall outside the 2SD limit for both SRMs in 2007. For SR3, there is an upward trend in the results whereas a downward trend is suggested for SR8, with values falling closer to the ISO median value of 0.29 %N. Taken overall, the values for the repeated SRM analyses fall within acceptable Quality Control limits and there is no evidence to indicate a consistent bias in the results.

4.2.2 Reporting

Soil N concentration data (0-15 cm) have been analysed to provide information on the state of soil N concentration in 2007 and the change since 1998. The statistical approach used for analysing the data for change involved bootstrapping which allows for non-normality in the data without the necessity of knowing details of the actual distribution. As such it provides a more accurate measurement of significance. Annex F of Emmett *et al.* (2008) provides a background document describing this approach.

The data in this report describe mean soil N concentrations in soils (0-15 cm) in 2007 and change since 1998 by Broad Habitat, Aggregate Vegetation Class (AVC) and Loss-on-Ignition (LOI) category for Great Britain (GB) and for the individual countries. In summary these are defined as:

- Broad Habitat - The Broad Habitat classification consists of 27 habitats which account for the entire land surface of Great Britain, and the surrounding sea. Countryside Survey reports on soils for 10 major terrestrial habitats.
- Aggregate Vegetation Class (AVC) – is a high level grouping of vegetation types produced from a quantitative hierarchical classification of the different plant species found in the original Countryside Survey sample plots
- Loss on ignition (LOI) category – soil type based on soil organic matter content defined as mineral (0-8% LOI; 0-44 g C kg^{-1}), humus-mineral (8 – 30% LOI ; 44-165 g C kg^{-1}), organo-mineral (30 – 60% LOI; 165-330 g C kg^{-1}) and organic (60 – 100%; > 330 g C kg^{-1})

To remove the effects of large-scale vegetation and / or land use change mean soil N concentrations have also been estimated for plots where the AVC has not changed over time. The AVC is only known for the survey years and may change during intervening periods for example due to arable-grassland rotation. The plots where the AVC has not changed can therefore be regarded as plots where the vegetation has been largely consistent in 1978, 1998 and 2007.

Soil (0-15 cm) total N density (t/ha) has been estimated for 2007 using the total N concentration and the bulk density data. These values are reported using the same categories for GB and individual countries. Total N density has not been estimated for AVC unchanged, as change in density cannot be reported.

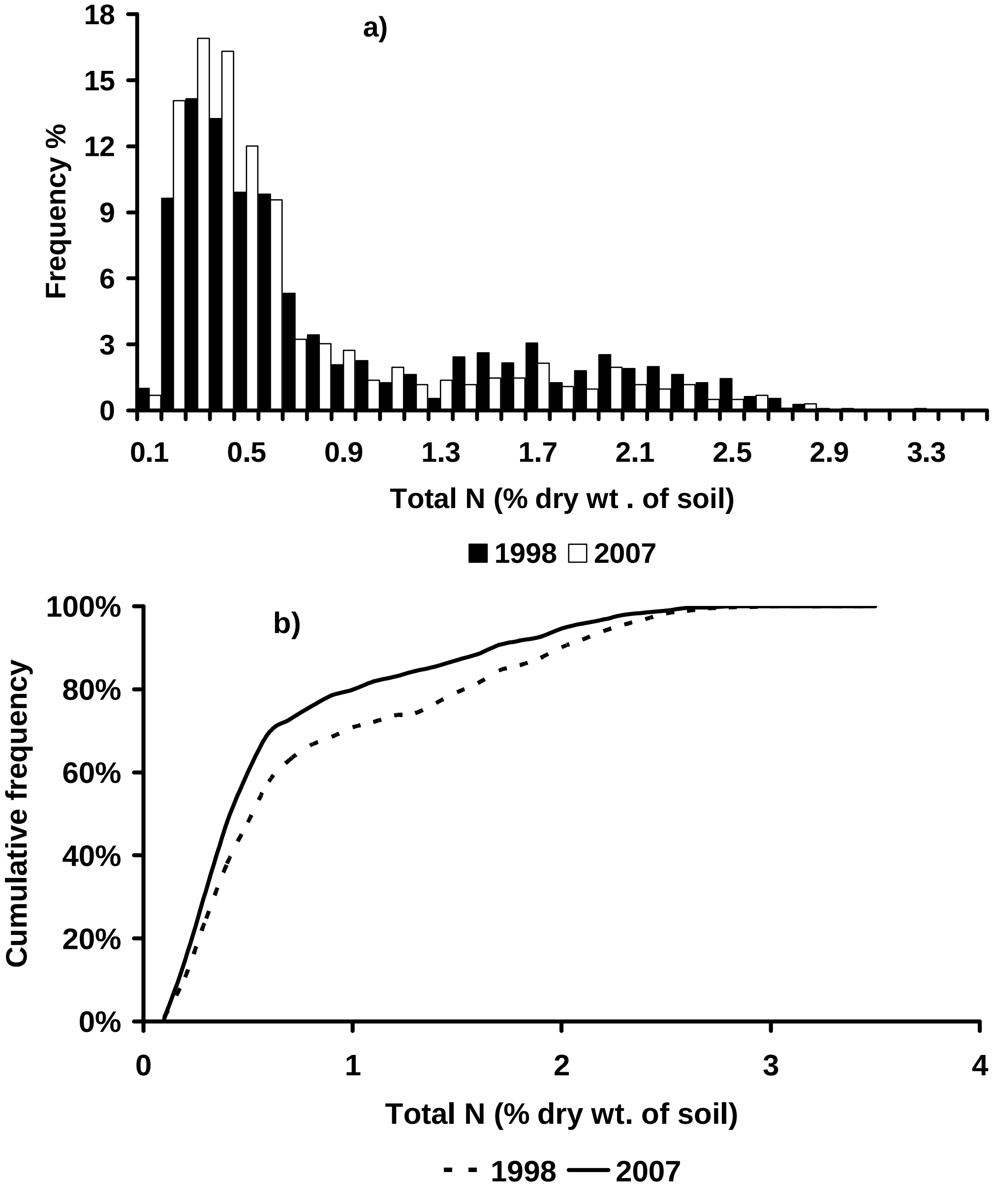
4.3 Results

4.3.1 Structure of the total nitrogen concentration data

Total N concentration was measured in samples from 1024 plots in 2007 and from 1110 plots in 1998; 75% of plots sampled in 2007 had also been sampled in 1998. Concentrations of total N measured in soils (0-15 cm) in 2007 ranged between 0.04 and 2.77%N compared to a range of values between 0.08 and 3.22 %N in 1998. The common practice in agricultural soils to determine N on a volume basis (mg/litre) makes comparison difficult particularly when combined with different depth of 0-7.5cm compared to 0-15cm in CS for grassland soils although ranges for CS soils seem broadly comparable.

Between 1998 and 2007, the proportion of samples with a total N concentration of 1%N or less increased from 71% to 80%, whilst the proportion of samples with greater than 2%N decreased from 9% to 5.4%. Overall, there was evidence of a downward shift in total N concentrations across the entire range of values between 1998 and 2007 ***(Fig. 4.2)***. The populations in 1998 and 2007 were skewed and slightly bimodal.

Figure 4.2: Distribution of soil (0-15cm) N concentrations a) Histogram for 1998 and 2007 b) Cumulative frequency for 1998 and 2007. Histogram frequencies normalised to percentage of total number of samples analysed in each survey.



Soil N concentration was strongly and positively correlated to loss on ignition (r^2 = 0.89) although there was more scatter in both datasets at higher values of LOI and total N ***(Fig. 4.3a)***. Total N concentration decreased with increasing bulk density in a logarithmic relationship (r^2 = 0.79; ***Fig. 4.3b***) and together the results show, not unexpectedly, that peaty soils with low bulk density contain the highest concentrations of N. Below pH 5.5, soil N concentrations varied across the full range of values measured (0.4 to 2.8%N) whilst above pH 6, the majority of samples contained between 0.1 and 0.6 %N ***(Fig. 4.3c)***. There was no clear relationship between total N concentration and Olsen-P ***(Fig. 4.3d)***. A wide range of total N values were encountered at Olsen-P concentrations below 50 mgP kg^{-1}, although samples with very high Olsen-P values, in excess of 150 mgP kg^{-1}, generally had low total N concentrations (<0.5 %N).

Figure 4.3: Relationships between soil N concentration in 2007 and a) Loss-on-ignition, b) bulk density, c) soil pH and d) Olsen-P concentration.

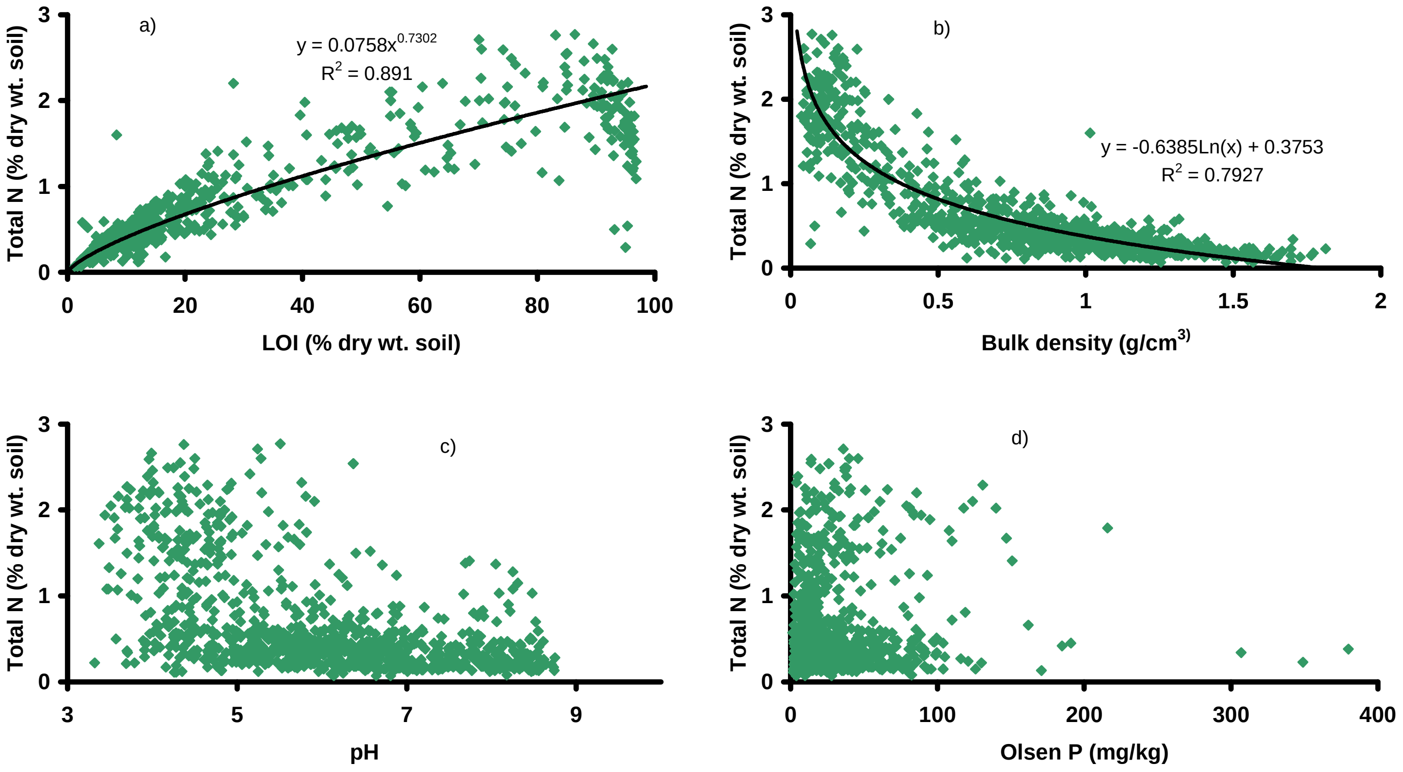
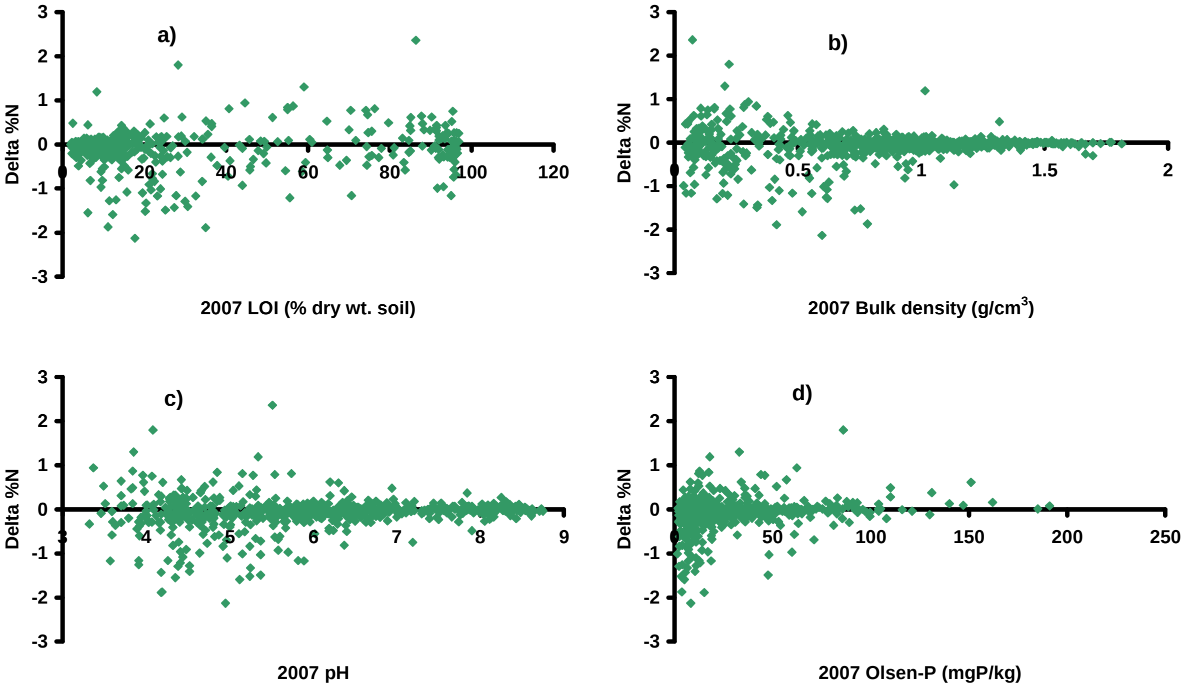


Figure 4.4: Plots of soil N concentration change between 1998 and 2007 (Delta soil N concentration) and 2007 values for a) Loss-on-ignition, b) bulk density, c) soil pH and d) Olsen-P concentration.



Changes in soil N concentration between 1998 and 2007 occurred across the full range of LOI concentrations ***(Fig. 4.4a)*** whereas large changes were more prevalent in soils with a bulk density below ≈0.7 g/cm^3 and pH less than 5.5 ***(Figs. 4.4b and 4.4c)***. Soils with relatively low Olsen-P concentrations (<20 mgP kg^{-1}) showed the largest decrease in total N concentration ***(Fig. 4.4d)*** with decreases of up to 2%N.

4.3.2. Change in mean total nitrogen concentration in soils (0-15 cm) across Great Britain

There was a significant, approximately 10% decrease in soil (0-15 cm) N concentration between 1998 and 2007 across GB as a whole ***(Table 4.2).*** This was reflected in many Broad Habitats. The magnitude of change varied between Broad Habitats with the smallest significant decrease (7%) measured in Arable which also had the lowest soil N concentrations in 1998 (0.27 %N) and 2007 (0.25 %N). The biggest percentage decrease between the surveys (21%) occurred in Coniferous Woodland. The highest soil N concentrations in both surveys were measured in soils in the Bog Broad Habitat (1.78 %N in 1998 and 1.59 %N in 2007). The soil N concentration in soils (0-15 cm) beneath Broadleaved Woodland, Improved Grassland, Bracken and Fen, Marsh and Swamp did not change significantly between 1998 and 2007.

The largest total N density (6.0 t/ha) was measured in Improved Grassland reflecting the intermediate mean N concentration and relatively high bulk density. Despite having the highest mean total N concentration, soils in the Bog and Coniferous Woodland had the lowest N densities (3.8 t/ha) due to the low bulk density values in these Broad Habitats.

There was a significant decrease in soil N concentration in all AVCs except Lowland Woodland, Tall Grass and Herb and Crops and Weeds between 1998 and 2007 ***(Table 4.2b)***. The lowest soil N concentrations were observed in Crops and Weeds in 1998 (0.26 %N) and 2007 (0.25 %N), whilst Heath and Bog AVC had the highest mean values in 1998 (1.7 %N) and 2007 (1.47 %N). The soil N concentrations in soils (0-15 cm) for plots in which the AVC did not change (***Table 4.2c)*** were broadly consistent with the dataset as a whole (***Table 4.2b***). Significant changes were only observed in Heath and Bog and Infertile Grassland for the unchanged dataset. This suggests that some of the significant change in soil N concentrations observed in the dataset as a whole may have arisen because of a change in land use between the surveys.

Heath and Bog AVC had the lowest total N density in 2007 (3.8 t/ha) and Fertile Grassland the highest (5.9 t/ha). These values compare closely with values measured in Bog and Improved Grassland Broad Habitats respectively.

Soil N concentrations decreased significantly across all LOI categories ***(Table 4.2d; Fig. 4.5)***, with the largest change observed in organo-mineral soils where mean total N in soils (0-15 cm) declined by more than 20%. In both surveys, the highest soil N concentrations were observed in organic soils which accounted for the high concentrations measured in Broad Habitats and AVCs with organic-rich soils (Dwarf Shrub Heath and Bog Broad Habitats, Moorland Grass Mosaic and Heath and Bog AVCs). Organic soils had the lowest total N density (3.8 t/ha) while the highest density was observed in humus-mineral soils (6.0 t/ha).

The soil N concentration data were combined with C data to calculate changes in soil C:N ratio (0-15cm). The C:N variable provides information on the relative change in C and N storage in soils. The general trend across all Broad Habitats is for no change or an increase in C:N ratio (***Table 4.3***).

Table 4.2: Change between 1998 and 2007 in N concentration of soils (0-15 cm) and total N density of soils (0-15 cm) in 2007 for GB for a) Broad Habitats, b) Aggregate Vegetation Classes (AVC) c) AVCs unchanged since 1978 and d) LOI categories. Arrows denote a significant change ($p<0.05$) in the direction shown. Diagonal line indicates too few samples to provide reliable value.

a) Great Britain – Broad Habitat

Broad Habitats	Mean Total Nitrogen (% dry wt. soil)		Direction of significant changes	Total Nitrogen density (t/ha)
	1998	2007	1998 - 2007	2007
Broadleaved, Mixed and Yew Woodland	0.70	0.65		5.1
Coniferous Woodland	1.12	0.88	↓	3.8
Arable and Horticulture	0.27	0.25	↓	4.3
Improved Grassland	0.47	0.45		6.0
Neutral Grassland	0.52	0.47	↓	5.6
Acid Grassland	1.49	1.23	↓	5.1
Bracken	0.84	0.95		/
Dwarf Shrub Heath	1.31	1.14	↓	4.7
Fen, Marsh and Swamp	1.22	1.08		4.8
Bog	1.78	1.59	↓	3.8
All Habitat Types	0.79	0.71	↓	4.9

b) Great Britain – AVC whole dataset

Aggregate Vegetation Class	Mean Total Nitrogen (% dry wt. soil)		Direction of significant changes	Total Nitrogen density (t/ha)
	1998	2007	1998 - 2007	2007
Upland Woodland	0.91	0.73	↓	4.0
Lowland Woodland	0.60	0.58		5.1
Fertile Grassland	0.44	0.41	↓	5.9
Infertile Grassland	0.57	0.52	↓	5.8
Moorland Grass Mosaic	1.28	1.13	↓	4.8
Heath and Bog	1.70	1.47	↓	3.8
Tall Grass and Herb	0.36	0.36		4.8
Crops and Weeds	0.26	0.25		4.3

c) Great Britain – AVC unchanged

Aggregate Vegetation Class	Mean Total Nitrogen (% dry wt. soil)		Direction of significant changes	Total Nitrogen density (t/ha)
	1998	2007	1998 - 2007	2007
Upland Woodland	0.90	0.72		/
Lowland Woodland	0.65	0.67		/
Fertile Grassland	0.47	0.44		/
Infertile Grassland	0.59	0.53	↓	/
Moorland Grass Mosaic	1.38	1.24		/
Heath and Bog	1.70	1.51	↓	/
Tall Grass and Herb	0.32	0.32		/
Crops and Weeds	0.25	0.24		/

d) Great Britain – Loss on Ignition category				
LOI category (%)	Mean Total Nitrogen (% dry wt. soil)		Direction of significant changes	Total Nitrogen density (t/ha)
	1998	2007	1998 - 2007	2007
Mineral (0-8)	0.29	0.27	↓	4.4
Humus-mineral (8-30)	0.60	0.56	↓	6.0
Organo-mineral (30-60)	1.46	1.14	↓	5.1
Organic (60-100)	1.91	1.80	↓	3.8

Figure 4.5: Change in soil (0-15 cm) N concentration across LOI categories in Great Britain between 1998 and 2007. Significant changes are shown as *** p<0.001; ** p<0.01; * p<0.05. 95% CI are shown for each bar.

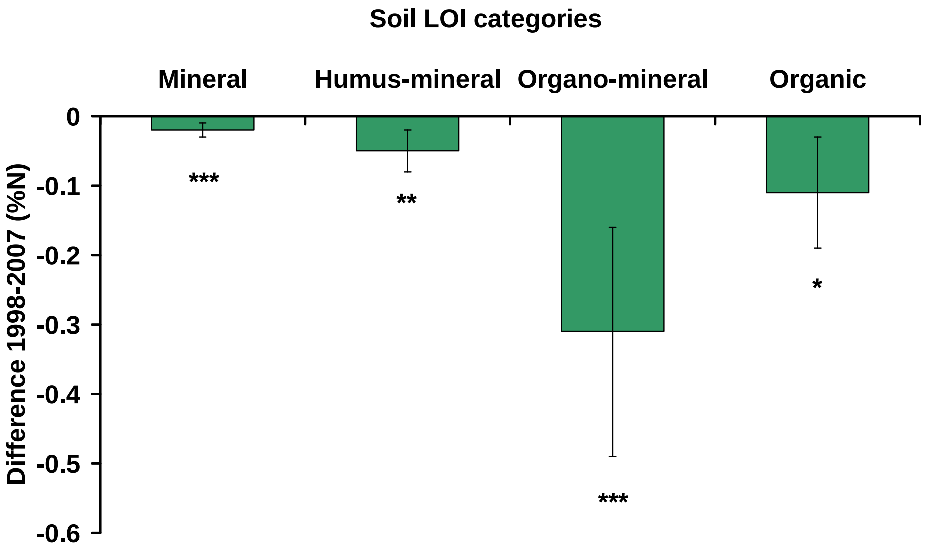


Table 4.3: Change in C/N ratio of soils (0-15 cm) across Great Britain for a) Broad Habitats, b) Aggregate Vegetation Classes (AVC) c) AVCs unchanged since 1978 and d) LOI categories. Arrows denote a significant change ($p<0.05$) in the direction shown.

a) Great Britain – Broad Habitat

Broad Habitats	Mean C/N ratio		Direction of significant changes
	1998	2007	1998 - 2007
Broadleaved, Mixed and Yew Woodland	14.0	14.2	
Coniferous Woodland	20.1	21.5	↑
Arable and Horticulture	11.7	11.3	↓
Improved Grassland	11.8	12.0	
Neutral Grassland	12.3	12.7	↑
Acid Grassland	17.7	18.2	
Bracken	15.2	16.5	
Dwarf Shrub Heath	22.9	23.1	
Fen, Marsh and Swamp	16.4	17.7	
Bog	26.2	28.2	
All Habitat Types	15.6	16.0	↑

b) Great Britain – AVC whole dataset

Aggregate Vegetation Class	Mean C/N ratio		Direction of significant changes
	1998	2007	1998 - 2007
Upland Woodland	17.9	19.3	↑
Lowland Woodland	13.4	14.2	
Fertile Grassland	11.7	12.1	
Infertile Grassland	12.4	13.0	↑
Moorland Grass Mosaic	18.9	19.6	
Heath and Bog	26.0	26.8	
Tall Grass and Herb	11.7	11.8	
Crops and Weeds	11.8	11.3	↓

c) Great Britain – AVC unchanged

Aggregate Vegetation Class	Mean C/N ratio		Direction of significant changes
	1998	2007	1998 - 2007
Upland Woodland	17.1	18.3	
Lowland Woodland	14.0	15.0	
Fertile Grassland	11.7	12.2	
Infertile Grassland	12.4	13.0	↑
Moorland Grass Mosaic	19.0	19.9	
Heath and Bog	27.3	29.4	
Tall Grass and Herb	11.5	12.0	
Crops and Weeds	11.7	11.2	↓

d) Great Britain – Loss on Ignition category

LOI category (%)	Mean C/N ratio		Direction of significant changes
	1998	2007	1998 - 2007
Mineral (0-8)	11.7	11.6	
Humus-mineral (8-30)	13.4	14.2	↑
Organo-mineral (30-60)	19.4	20.4	
Organic (60-100)	26.6	27.8	

4.3.3. Change in mean total nitrogen concentration in soils (0-15 cm) across England

Total N concentration was measured only on the Main Plots within the original 256 squares sampled in 1978, giving a maximum potential sample number of 1281 of which 1024 were sampled in 2007 and 1110 in 1998. For this reason sample numbers decline rapidly in country-level data analysis. A minimum cut-off of 20 samples was applied for country-level analysis of total N concentration by Broad Habitat, AVC and LOI Category. As a result, there are several gaps in the results. Missing data are denoted by a horizontal line across the cell in the table.

There was a relatively small (11.5%) but significant decrease in soil N concentration across the All Broad Habitats category in England between 1998 and 2007 ***(Table 4.4a)***. Arable soils (0-15 cm) contained the lowest soil N concentrations in England in 1998 (0.27 %N) and 2007 (0.25 %N), and there was a small (7%) but significant decrease between the two surveys. Soil N concentrations in soils (0-15 cm) beneath Improved Grassland and Neutral Grassland in England were very similar in 2007 (≈ 0.48 %N) and a significant decrease in concentration was observed in the latter between 1998 and 2007 ***(Table 4.4a)***. No significant changes were observed in N concentrations in soils (0-15 cm) beneath Broadleaved, Mixed and Yew Woodland and Acid Grassland in England between 1998 and 2007. There were insufficient samples to make a valid estimate of the mean and change in N concentration in soils (0-15 cm) in the remaining Broad Habitats in England.

Total N density was lowest in the Arable Broad Habitat (4.4 t/ha) and highest in Improved Grassland (6.1 t/ha); these figures were very similar to the data for these Broad Habitats across GB ***(Table 4.2a)***.

There were significant decreases in soil N concentration in Fertile Grassland and Infertile Grassland AVCs in England between 1998 and 2007 ***(Table 4.4b)***. Of the AVCs with sufficient data to provide a valid estimate of the mean, the highest concentrations in 1998 and 2007 were measured in soils (0-15 cm) beneath Moorland Grass Mosaic (1.09 %N). The highest total N density was measured in Infertile Grassland AVC (6.1 t/ha) whilst Upland Woodland and Crops and Weeds jointly had the lowest total N density (4/3 t/ha).

Restricting the analysis to plots where AVC remained unchanged, resulted in only three AVCs having sufficient samples for statistically valid estimates of the mean ***(Table 4.4c)***. Infertile Grassland was the only AVC showing a significant reduction in mean soil N concentration between 1998 and 2007. Mean values for Fertile Grassland and Crops and Weeds for the unchanged dataset were very similar to those for the dataset as a whole.

There was small (≈10%) but significant decrease in soil N concentration in mineral and humus-mineral soils in England between 1998 and 2007 ***(Table 4.4d)***. Organo-mineral soils did not change significantly between the surveys and there were insufficient data to provide valid estimates for organic soils in England. The lowest total N density was observed in mineral soils (4.5 t/ha) and humus-mineral soils contained the most total N (6.7 t/ha).

Table 4.4: Change between 1998 and 2007 in N concentration of soils (0-15 cm) and total N density of soils (0-15 cm) in 2007 for England for a) Broad Habitats, b) Aggregate Vegetation Classes (AVC) c) AVCs unchanged since 1978 and d) LOI categories. Arrows denote a significant change ($p<0.05$) in the direction shown. Diagonal line indicates too few samples to provide reliable estimate.

a) England – Broad Habitat

Broad Habitats	Mean Total Nitrogen (% dry wt. soil)		Direction of significant changes	Total Nitrogen density (t/ha)
	1998	2007	1998 - 2007	2007
Broadleaved, Mixed and Yew Woodland	0.64	0.58		5.6
Coniferous Woodland	/	/	/	/
Arable and Horticulture	0.27	0.25	↓	4.4
Improved Grassland	0.47	0.45		6.1
Neutral Grassland	0.52	0.46	↓	5.9
Acid Grassland	1.10	0.92		5.4
Bracken	/	/	/	/
Dwarf Shrub Heath	/	/	/	/
Fen, Marsh and Swamp	/	/	/	/
Bog	/	/	/	/
All Habitat Types	0.52	0.46	↓	5.3

b) England – AVC whole dataset

Aggregate Vegetation Class	Mean Total Nitrogen (% dry wt. soil)		Direction of significant changes	Total Nitrogen density (t/ha)
	1998	2007	1998 - 2007	2007
Upland Woodland	1.06	0.89		4.3
Lowland Woodland	0.61	0.60		5.3
Fertile Grassland	0.45	0.39	↓	5.9
Infertile Grassland	0.56	0.51	↓	6.1
Moorland Grass Mosaic	1.09	1.09		5.8
Heath and Bog	/	/	/	/
Tall Grass and Herb	0.36	0.37		4.9
Crops and Weeds	0.27	0.25		4.3

c) England – AVC unchanged

Aggregate Vegetation Class	Mean Total Nitrogen (% dry wt. soil)		Direction of significant changes	Total Nitrogen density (t/ha)
	1998	2007	1998 - 2007	2007
Upland Woodland	/	/	/	/
Lowland Woodland	/	/	/	/
Fertile Grassland	0.49	0.45		
Infertile Grassland	0.60	0.55	↓	
Moorland Grass Mosaic	/	/	/	/
Heath and Bog	/	/	/	/
Tall Grass and Herb	/	/	/	/
Crops and Weeds	0.25	0.24		

d) England – Loss on Ignition category

LOI category (%)	Mean Total Nitrogen (% dry wt. soil)		Direction of significant changes	Total Nitrogen density (t/ha)
	1998	2007	1998 - 2007	2007
Mineral (0-8)	0.29	0.26	↓	4.5
Humus-mineral (8-30)	0.62	0.56	↓	6.7
Organo-mineral (30-60)	1.45	1.10		6.3
Organic (60-100)	/	/	/	/

4.3.4 Change in mean total nitrogen concentration in soils (0-15 cm) across Scotland

In Scotland there was a small (11%) but significant decline in soil N concentration for the All Broad Habitats category ***(Table 4.5a)*** between 1998 and 2007. Significant decreases in N concentration in soils (0-15 cm) were also observed in Coniferous Woodland, Acid Grassland, Dwarf Shrub Heath and Bog Broad Habitats, but there were no significant changes in soil N concentration in Broadleaf Woodland, Arable, Improved Grassland and Neutral Grassland. Improved Grassland contained the most total N (5.2 t/ha) and Coniferous Woodland had the lowest total N density (3.7 t/ha). The figure for Coniferous Woodland is comparable with that for GB, but Improved Grassland in Scotland contains 0.8 t/ha less total N compared to GB.

Infertile Grassland and Heath and Bog AVCs all showed a significant decrease in total N concentration between 1998 and 2007 ***(Table 4.5b)***. There were no significant changes in Upland Woodland, Moorland Grass Mosaic, Fertile Grassland or Crops and Weeds. The latter contained the smallest soil N concentrations in 1998 and 2007 (0.24 %N and 0.23 %N respectively) whilst the highest mean concentrations were measured in Heath and Bog (1.48 %N in 2007). Despite the high mean soil (0-15 cm) %N, Heath and Bog had the lowest total N density (3.6 t/ha) reflecting the relatively low bulk density of organic-rich soils. Infertile Grassland contained the largest quantity of soil (0-15 cm) N (5.2 t/ha).

Restricting the analysis to unchanged AVCs removed the Crops and Weeds AVC, but for the other AVCs, the results were consistent with those for the dataset as a whole ***(Table 4.5c)***.

Table 4.5: Change between 1998 and 2007 in N concentration of soils (0-15 cm) and total N density of soils (0-15 cm) in 2007 for Scotland for a) Broad Habitats b) Aggregate Vegetation Classes (AVC) c) AVCs unchanged since 1978 and d) LOI categories. Arrows denote a significant change (p<0.05) in the direction shown. Diagonal line indicates too few samples to provide reliable value.

a) Scotland – Broad Habitat

Broad Habitats	Mean Total Nitrogen (% dry wt. soil)		Direction of significant changes	Total Nitrogen density (t/ha)
	1998	2007	1998 - 2007	2007
Broadleaved, Mixed and Yew Woodland	0.81	0.76		4.0
Coniferous Woodland	1.11	0.92	↓	3.7
Arable and Horticulture	0.26	0.26		4.1
Improved Grassland	0.45	0.43		5.2
Neutral Grassland	0.52	0.46		4.9
Acid Grassland	1.63	1.34	↓	4.6
Bracken	/	/	/	/
Dwarf Shrub Heath	1.34	1.17	↓	4.2

Fen, Marsh and Swamp				
Bog	1.78	1.58	↓	3.8
All Habitat Types	1.12	1.00	↓	4.3

b) Scotland – AVC whole dataset

Aggregate Vegetation Class	Mean Total Nitrogen (% dry wt. soil)		Direction of significant changes	Total Nitrogen density (t/ha)
	1998	2007	1998 - 2007	2007
Upland Woodland	0.82	0.70		3.8
Lowland Woodland				
Fertile Grassland	0.40	0.37		5.1
Infertile Grassland	0.64	0.54	↓	5.2
Moorland Grass Mosaic	1.27	1.12		4.5
Heath and Bog	1.72	1.48	↓	3.6
Tall Grass and Herb				
Crops and Weeds	0.24	0.23		4.2

c) Scotland – AVC unchanged

Aggregate Vegetation Class	Mean Total Nitrogen (% dry wt. soil)		Direction of significant changes	Total Nitrogen density (t/ha)
	1998	2007	1998 - 2007	2007
Upland Woodland	0.86	0.75		
Lowland Woodland				
Fertile Grassland	0.44	0.41		
Infertile Grassland	0.63	0.52	↓	
Moorland Grass Mosaic	1.43	1.24		
Heath and Bog	1.72	1.53	↓	
Tall Grass and Herb				
Crops and Weeds				

d) Scotland – Loss on Ignition category

LOI category (%)	Mean Total Nitrogen (% dry wt. soil)		Direction of significant changes	Total Nitrogen density (t/ha)
	1998	2007	1998 - 2007	2007
Mineral (0-8)	0.27	0.25		3.9
Humus-mineral (8-30)	0.58	0.53		5.0
Organo-mineral (30-60)	1.44	1.11	↓	4.5
Organic (60-100)	1.89	1.78	↓	3.6

There was no significant change in soil N concentration of mineral and humus-mineral soils in Scotland between 1998 and 2007 ***(Table 4.5d)***. Soil N concentration decreased significantly by over 20% in organo-mineral soils, but there was a much smaller (6%) significant decrease in organic soils between 1998 and 2007. The highest soil N concentrations in 1998 and 2007 were observed in organic soils (1.89 %N and 1.78 %N respectively); these had the lowest total N density in 2007 (3.6 t/ha). Humus-mineral soils contained the most N (5.0 t/ha) in Scotland.

4.3.5 Change in mean total nitrogen concentration in soils (0-15 cm) across Wales

The small number of samples from Wales placed a major restriction on data analysis, with only seven reporting categories having sufficient data to report valid statistics for status and change in soil N concentration ***(Table 4.6)***. There was no significant change in soil N concentration across Wales as a whole between 1998 and 2007 ***(Table 4.6a)***. Improved Grassland was the only Broad Habitat to have sufficient data to provide stock and change statistics in Wales and this showed no significant change in soil N concentration between 1998 and 2007. Total N density in Improved Grassland in Wales in 2007 (7.2 t/ha) was relatively high compared with other countries and with GB as a whole. For Wales as a whole, total N density was 6.1 t/ha in 2007 which was a comparatively high figure and reflected the pre-dominance in Wales of samples from Improved Grassland (43% of samples) and the virtual absence of samples from Broad Habitats with more organic-rich soils which have a lower total N density.

Infertile Grassland and Fertile Grassland were the only AVCs in Wales to have sufficient sample points to provide valid statistics for stock and change ***(Tables 4.6 b and 4.6c)***. Mean concentrations of total N did not change significantly between 1998 and 2007 in either AVC. The largest total N density was measured in Fertile Grassland (7.5 t/ha); this was the highest value for this AVC of all three countries. Restricting the dataset to unchanged AVCs ***(Table 4.6c)*** reduced the number of reporting categories to Infertile Grassland and mean soil N concentration did not change between 1998 and 2007.

There were no significant changes in mean soil N concentrations in mineral and humus-mineral soils in Wales between 1998 and 2007 ***(Table 4.6d)***. These were the only soil LOI categories to have sufficient samples to report status and change. Total N densities in 2007 in mineral and humus-mineral soils were 5.3 t/ha and 6.4 t/ha respectively.

Table 4.6: Change between 1998 and 2007 in N concentration of soils (0-15 cm) and total N density of soils (0-15 cm) in 2007 for Wales for a) Broad Habitats, b) Aggregate Vegetation Classes (AVC) c) AVCs unchanged since 1978 and d) LOI categories. Absence of arrows denote no significant change (p<0.05) were observed. Diagonal line indicates too few samples to provide reliable value.

a) Wales – Broad Habitat

Broad Habitats	Mean Total Nitrogen (% dry wt. soil)		Direction of significant changes	Total Nitrogen density (t/ha)
	1998	2007	1998 - 2007	2007
Broadleaved, Mixed and Yew Woodland				
Coniferous Woodland				
Arable and Horticulture				
Improved Grassland	0.57	0.57		7.2
Neutral Grassland				
Acid Grassland				
Bracken				
Dwarf Shrub Heath				
Fen, Marsh and Swamp				
Bog				
All Habitat Types	0.74	0.70		6.1

b) Wales – AVC whole dataset

Aggregate Vegetation Class	Mean Total Nitrogen (% dry wt. soil)		Direction of significant changes	Total Nitrogen density (t/ha)
	1998	2007	1998 - 2007	2007
Upland Woodland				
Lowland Woodland				
Fertile Grassland	0.54	0.56		7.5
Infertile Grassland	0.56	0.55		6.1
Moorland Grass Mosaic				
Heath and Bog				
Tall Grass and Herb				
Crops and Weeds				

c) Wales – AVC unchanged

Aggregate Vegetation Class	Mean Total Nitrogen (% dry wt. soil)		Direction of significant changes	Total Nitrogen density (t/ha)
	1998	2007	1998 - 2007	2007
Upland Woodland				
Lowland Woodland				
Fertile Grassland				
Infertile Grassland	0.51	0.51		
Moorland Grass Mosaic				
Heath and Bog				
Tall Grass and Herb				
Crops and Weeds				

d) Wales – Loss on Ignition category

LOI category (%)	Mean Total Nitrogen (% dry wt. soil)		Direction of significant changes	Total Nitrogen density (t/ha)
	1998	2007	1998 - 2007	2007
Mineral (0-8)	0.35	0.35		5.3
Humus-mineral (8-30)	0.61	0.59		6.4
Organo-mineral (30-60)				
Organic (60-100)				

4.4 Discussion and Policy Implications

The policy question which led to the inclusion of this parameter in the CS in 2007 was; "Can the eutrophication trend in the countryside be detected in the soil as well as the vegetation using this basic soil property?" As there were no significant increases in mean soil N concentration in any reporting category in GB or in the individual countries between 1998 and 2007 the conclusion must be a negative. Instead, significant decreases in soil N concentration were detected for many reporting categories. The decreases for woodlands and semi-natural habitats were generally small (5-10% of 1998 levels) with a maximum of 21% in Coniferous Woodland. In intensively managed soils the question of interest, although not specified would have been; "Can the decline in fertiliser use in improved grassland and cropland be detected in the soil using this basic soil property? ". There is not as clear evidence for this, as might have been expected, with no change or a small decline (4-7% of 1998 levels) observed.

For semi-natural and woodland systems, the results imply that sustained levels of atmospheric N deposition over the decade from 1998 to 2007 have not resulted in measurable increases in soil (0-15 cm) N concentration as expected. Average inputs across GB are ca. 20 kgN/ha/yr which is equivalent to 0.18tN/ha. This translates to a potential increase of ca. 3-4% in soil nitrogen concentrations (0-15cm). In contrast to the expected increase in soil N concentration there was a significant decline in many habitats. The trend for increased C:N ratios (significant for Coniferous Woodland and Neutral Grassland) indicates that there is either increased removal of N from the soil by vegetation, leaching or gaseous pathways and / or greater inputs and storage of C due to increased plant productivity. Change in plant fixation of C and uptake of N may be driven by the combined and possibly interactive effects of N deposition and climate change on plant productivity. No significant increase in soil (0-15cm) carbon density was observed for any semi-natural habitat or woodland (Chapter 2) although there were positive trends observed for Acid Grassland, Dwarf Shrub Heath and Bog (**Table 2.5**).

For managed grasslands the overall trend is not clear. Whilst there was no change over this period in soil (0-15cm) nitrogen concentrations for Improved Grassland Broad Habitat there was a significant decline for the Fertile Grassland AVC for GB. No significant change in C:N was observed for either category. The relatively small signal observed is unexpected as fertiliser application rates to grassland declined dramatically by ≈ 40% to 65 kgN/ha between 1998 and 2007 (BSFP 2008). Taking England as an example, combined land use and fertiliser statistics showed a reduction in total use of N fertilisers between 1998 and 2007 of 33% for grassland. The grassland statistic for England combined the effects of a reduction in application rate (by c.40%) and a small (12%) increase in land area under grassland (June Agricultural Census data for 1998 and 2007). This result could imply either that livestock farmers are using alternative sources of N such as farm yard manure, slurries and other organic waste products to maintain N levels in managed grassland soils or soil (0-15 cm) %N is an insensitive indicator of soil response to changes in fertiliser use.

For cropped systems, a decline in %N and C:N ratios was observed suggesting the loss of soil C (0-15cm) reported in Chapter 2 is matched by a loss of N (9 and 7.5% respectively between 1998 and 2007). As there was only a small decline in N fertiliser application rates to tilled land across GB between 1998 and 2007 (e.g. in England 6% drop for tilled land), it is most likely that processes which would remove C and N in equal proportions may be responsible e.g. erosion or deep ploughing resulting in lower soil horizons characterised by lower C:N coming to the surface.

4.4.1 Policy implications

In semi-natural systems the decline in %N is contrary to expectations due to the ongoing input of N atmospheric deposition across the GB landscape at an average of *ca.* 20-30kgN/ha/yr (RoTAP, 2010). There may be either increased removal of N from the soil by vegetation, leaching or gaseous pathways and / or greater inputs and storage of C due to increased plant productivity. Increased loss of N is known to be linked to N inputs although evidence for this is currently limited for GB (RoTAP, 2010). Change in plant uptake of C and N may be driven by the combined and possible interactive effects of N deposition and climate change on plant productivity. Increased plant productivity is one of the primary drivers of vegetation composition change in semi-natural systems (NEGTAP, 2001; RoTAP, 2010). This apparent ‘dilution’ of the N signal in the soil may also have major implications for current soil and pollution monitoring programmes which rely on the gross soil measurements such as %N and C:N to indicate the impact of N deposition in semi-natural systems. A more sensitive indicator of plant available-N such as Mineralisable-N **(Chapter 5)** may need to be combined with plant productivity and vegetation composition change in the future. Ongoing analysis will help resolve the links between the changes in the C and N storage rates and the possible underlying drivers.

In improved grassland systems, the lack of any clear decline in %N despite a major reduction in N fertiliser use over the same period suggests farmers are using alternative sources of N such as slurry and other organic waste solids and / or that %N is an insensitive indicator of change in fertiliser use. If indeed farmers are continuing to maintain total soil N concentrations in managed grassland whilst reducing use of mineral N fertiliser this would be a positive outcome as the energy costs associated with mineral fertiliser use will have been reduced without detriment to soil N status. Fertiliser use is one of the indicators used by Defra to gauge progress in reducing the environmental cost of the food chain under the Sustainable Farming and Food Strategy. N fertiliser has been chosen because N contributes to diffuse pollution and fertiliser production has a high energy cost. However, there is a risk that the maintenance of soil N status, possibly through other sources of N, may limit the intended benefits of reduced fertiliser use for diffuse pollution control.

In cropped soils, the loss of soil C (0-15cm) reported in **Chapter 2** combined with the reported decline in soil N concentrations here suggest erosion, deep ploughing or increased decomposition may be responsible for the 7-9% reduction for C and N as there is little change in fertiliser application rates. This suggests that policies in place to protect soils in cropped system may not be adequate.

4.5 References

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5. Mineralisable-N

Summary

- **Mineralisable-N stock (kgN / ha) in soil (0-15cm) was a sensitive indicator of recognised differences in nitrogen availability between different vegetation types suggesting it is a promising indicator of eutrophication of the countryside.**
- **Initial investigations testing the link between mineralisable-N and occurrence of plant species in 45 test sites suggests it provides additional information to mean total nitrogen concentration data (%N) possibly linked to short term changes in nitrogen availability or specific vegetation or soil types.**
- **There were strong geographical trends in the proportion of mineralised-N transformed to the mobile form nitrate which suggest a close relationship to broad-scale climatic or soil parameters.**
- **Future analyses will separate out the inherent variability associated with climate, vegetation and soil type to identify spatial patterns which can be linked to atmospheric deposition and changes in management.**

5.1 Policy background

Policy question: Can the trend of eutrophication of the countryside be detected in the soil as well as the vegetation using this sensitive soil process method?

Measurements: Concentrations of ammonium- and nitrate-N in soil (0-15cm) after a standard incubation. The measurement was carried out for the first time in 2007. Soils were collected from plots included in the original 1978 survey. Countryside Survey (CS) in 2007 has provided:

- Whole GB and country-level assessment of soil mineralisable N status in 2007.
- Explanatory data to contribute to the analysis of other CS datasets such as those describing changes in plant species composition.
- Data likely to decrease uncertainty in model chains used to predict impacts of N deposition on biodiversity.

Changes in plant species composition, observed following CS in 1998, have been ascribed to eutrophication following increased deposition of atmospheric nitrogen (N) compounds (Braithwaite *et al.* 2006; Maskell *et al.* 2010). This eutrophication is unlikely to be closely linked to changes in soil total N and total C/N, since the soil N stock is large in relation to annual fluxes and contains much N that is not available to plants. The purpose of the measurement of mineralisable N within CS in 2007 is to develop a simple but robust index of plant-available N. This will help determine causal drivers of change in species composition, by linking measures of soil N status with plant species composition across a wide range of Broad Habitats, geographical locations and soil types. Mineralisable N measurements will also be used to improve models of soil biogeochemistry used at national scale to predict carbon (C) and N cycling and the effects of N pollution on biodiversity. The data will also be useful in identifying one aspect of nutrient cycling at a national scale between different habitats and the relationship to different drivers. Nutrient cycling is one of the ecosystem supporting services currently under review as part of the National Ecosystem Assessment.

Several types of analyses have been proposed to measure plant-available N, including measurements of net N mineralisation flux, gross mineralisation flux, and proxies such as near-infra-red absorption analysis. Plants are able to take up N even from soils with no net mineralisation flux, (e.g. Dyck *et al.* 1987), due to interception of available N before it can be re-immobilised. Such temporarily-available N pools can be measured using isotopic dilution or by adsorption onto strong ion-exchange resins, but these measurements probably overestimate plant-available N (Fierer *et al.* 2001). While net mineralisation measurements underestimate plant-available N in low-N systems, particularly where plants take up a substantial proportion of N in dissolved organic form, net N mineralisation remains useful to distinguish soils across a range of N availability (Schimel and Bennett 2004).

Plant species may vary in their preference for dissolved organic, reduced or oxidised N (Miller and Bowman 2003); species typical of infertile habitats are more likely to use dissolved organic N, whereas species typical of fertile habitats are more likely to be adapted for nitrate assimilation. Thus while mineralisable N is an index of plant available-N the two concepts do not correspond directly, since some plants use dissolved organic N directly, and also since plants exert some control over mineralisation and therefore N availability within the rhizosphere. The relative availability of ammonium and nitrate may be more important than gross fluxes for explaining species occurrence (Bengtson *et al.* 2006). A measure of net nitrification during incubation was also included to assess whether this distinguished soil types more clearly and to provide extra information for plant species occurrence models.

Policy decisions concerned with the abatement of atmospheric emissions of sulphur dioxide and oxidised and reduced forms of N are currently informed through the critical load approach. The general definition of the critical load is: “a quantitative estimate of an exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur according to present knowledge” (UNECE 2004). Critical loads for N are calculated using either empirical or steady-state mass balance approaches (UNECE 2004). Empirical approaches rely on data from experiments, with critical loads for each habitat agreed by consensus at an EU/UNECE level. However, neither of these approaches allows a timescale of changes to be identified, and so dynamic models are being developed to improve forecasting of both soil and plant species change. Hitherto, soil total N and total C have been used as the abiotic indicators of N availability that link biogeochemical and floristic parts of these models. These bulk measures only explain around 60% of the variation in mean Ellenberg N (a floristic indicator of eutrophication). Abiotic measurement of N status are thought to be the major source of uncertainty in such model chains (Wamelink *et al.* 2002). A more sensitive measurement of available N is required to provide a better indication of excessive N deposition and a more accurate predictor of floristic change, and improve the accuracy of model chains used to develop policy in relation to the UNECE process.

5.2 Methods

5.2.1 Proof of concept

Net mineralisation flux has generally been measured by comparing the amounts of extractable nitrate and ammonium before and after a period of incubation, using paired soil samples e.g. (Keeney 1980; Waring and Bremner 1964). Soil disturbance can change mineralisation and immobilisation rates, so methods that keep the core intact are preferred (Raison *et al.* 1987). However, the established method may be unsuitable for large surveys in which the transit of cores to the laboratory cannot be completely controlled, since mineralisation in transit is likely to lead to large variation in mineral N contents on arrival at the laboratory, which inevitably increases error in the calculation of net flux. For this reason a new method was developed during the CS in 2007 pilot study, in which soils were flushed through with approximately four pore-volumes of an artificial rain solution to remove any accumulation of mineral N during transit.

Water tension during incubation affects the mineralisation rate, and nitrification and denitrification fluxes and hence the ratio of ammonium to nitrate. Measuring water tension is time-consuming, and so calculating the amount of water that needs to be added or evaporated to reach a particular proportion of water-holding capacity for a given soil is not straightforward. Instead water tension was standardised to approximately that at field capacity, by applying suction to the saturated soil to drain the larger pores.

A pilot study showed that the new mineralisable N measurement greatly improved the prediction of floristic composition as represented by mean Ellenberg N score (Rowe *et al.* in prep). The method was applied to a large set of cores taken in CS in 2007. A full description of the method is given in the CS in 2007 Soils

Manual (Emmett *et al.* 2008). Three of the five Main Plots were selected for analysis at random from each of the original 256 CS squares. Access restrictions to some of the CS plots prevented collection of some cores, and 699 of the planned 768 analyses were carried out.

Three metrics were chosen to express measurements of mineral N, i.e. ammonium and nitrate contents. The total mineral N per g soil reflects availability to plants, but gives the impression of large available N contents in organic sols with low bulk density. Total mineral N per g organic matter may provide a better index of N availability, since large carbon contents are likely to inhibit the net release of mineral N from organic matter. Nitrate content after incubation is a measure of net nitrification (since N is initially released from organic matter in reduced forms). To separate this signal from that of overall quantity of mineral N, nitrate-N content was expressed as a proportion of total mineral N.

The rationale for including mineralisable N within the CS measurement suite is summarised in ***Table 5.1***.

Table 5.1: Summary of rationale for measurement of soil mineralisable nitrogen within CS in 2007.

Issue	Facts	Comments
History in CS	No measurements previously made	Better measure of plant-available N than total or soluble N
Country level reporting	No	Dataset confined to 1978 CS squares which limits the power of analysis for Country level reporting for habitat, vegetation and soil types stratifications.
Links and compatibility to other monitoring programmes	No known datasets at national scale	Linked to N storage and turnover, hence to water quality and floristic monitoring e.g. Environmental Change Network
Uniqueness of CS	No known datasets at national scale	Only integrated sample which can be linked to vegetation and land management
Value for money (Policy priority or interpretative value x cost)	Medium	High policy and interpretative value, medium cost

5.2.2 Analytical method

An extra soil core was taken in 2007 in addition to those taken in previous surveys, for mineralisable N analyses. A 15 cm long by 5 cm diameter plastic pipe was knocked into the ground to obtain this core, according to the detailed field protocol set out in (Emmett *et al.* 2008; Chapter 1). Once extracted and logged, the long white cores were returned by mail to CEH Bangor. Cores were stored at 4 ^{o}C until a sufficient number had been received for an analytical batch.

The lab protocol is set out in detail in (Emmett *et al.* 2008). In short, the plastic sampling pipe was split open, and the intact soil core laid on a perforated rack. The core was misted repeatedly with a solution with the same concentrations of major ions as UK rain in 2007 as estimated using the FRAME model (except with zero N concentrations) until approximately 150 ml solution had passed through. Suction was applied using a vacuum line to drain larger pores of solution. The core was wrapped in a thin plastic bag to restrict aeration, and incubated for four weeks at 10 ^{o}C. After the full 4 week incubation period, the core was carefully homogenised and a subsample extracted using a 1-molar solution of potassium chloride (KCl) for analysis of ammonium and nitrate content. Mineralisable N was expressed in mg N / kg dry soil.

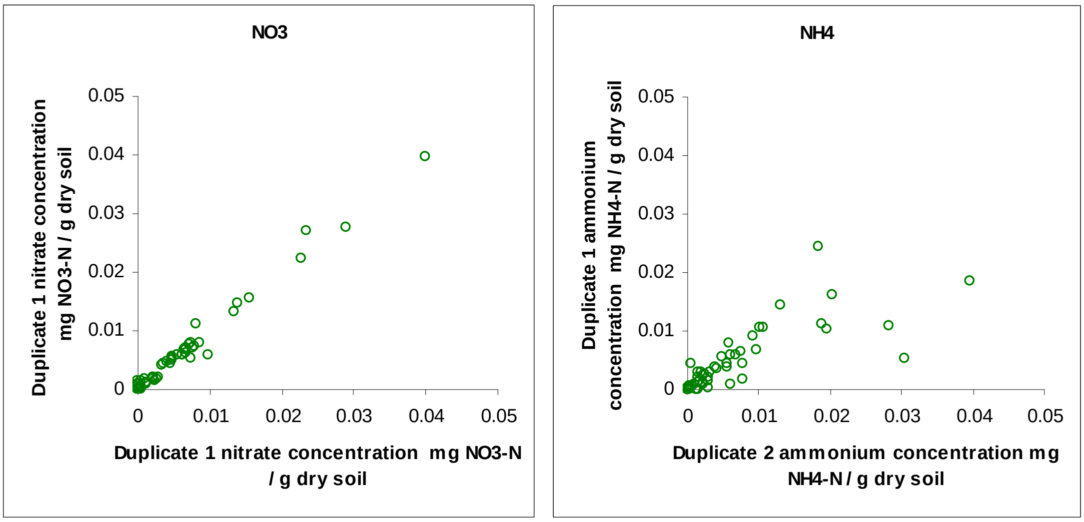
5.2.3 Quality assurance

Replicate cores were not available, but replicate subsamples were taken after incubation for KCl extraction and analysis from two cores per batch of approximately 30 samples. Two standard reference soils (CEH Bangor Reference Soils 1 and 2) were also analysed per batch. Several steps were taken to minimise potential artefacts by standardising sample collection, flushing, incubation and analysis. Initial mineral contents were standardised by flushing with a minus-N solution.

A standard amount of solution was passed through each core. This took less time for coarse-textured soils than for fine clay and peat soils. To standardise temperature conditions during the flushing step, all cores were retained in the flushing room at 4 ^{o}C for the same length of time.

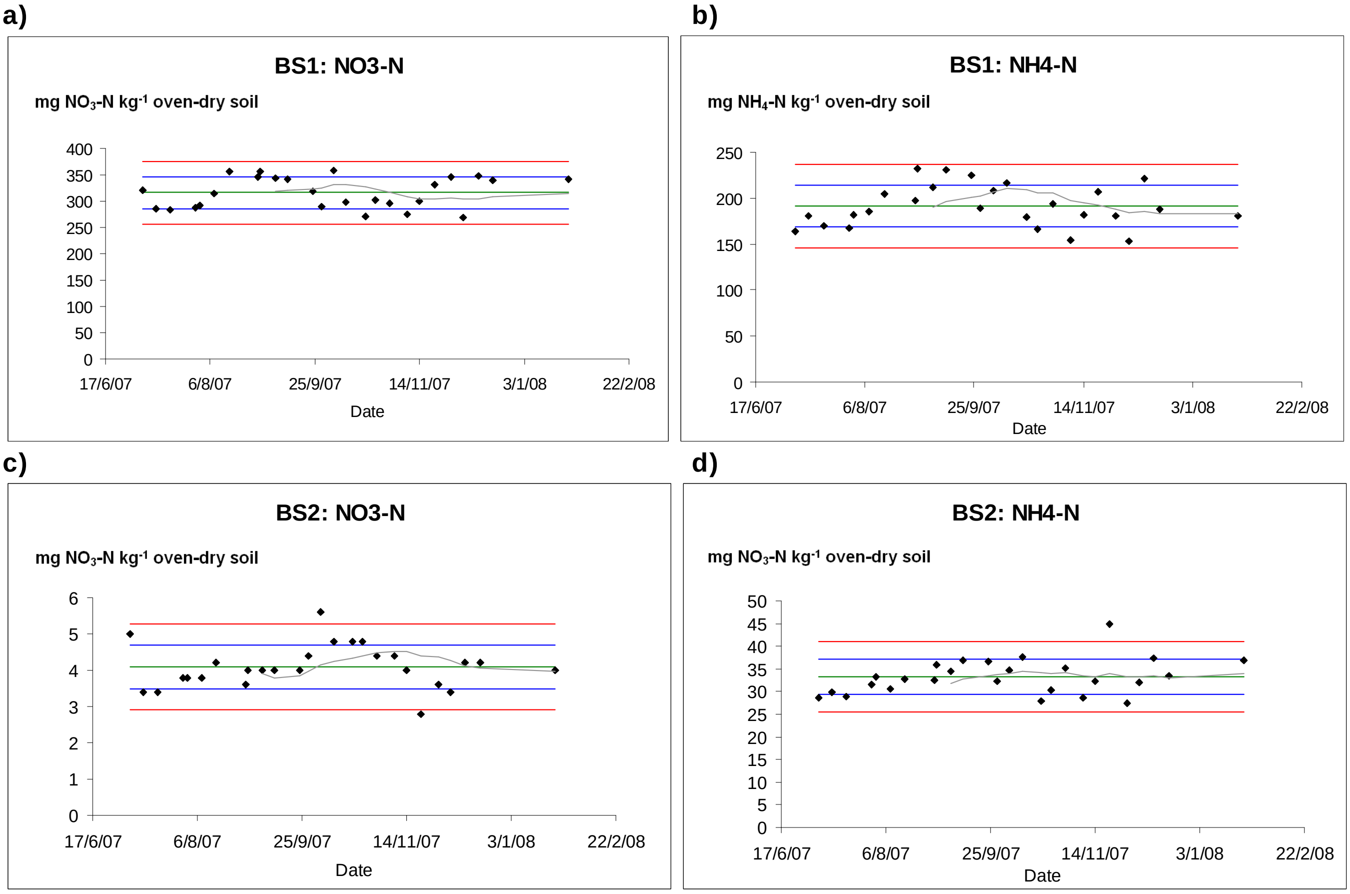
Incubation took place under standard conditions of temperature and aeration, and for a standard time. The duplicate analyses undertaken on replicate subsamples were very consistent for nitrate (R^2 = 98 %), but not as good for ammonium (R^2 = 63 %) ***(Fig. 5.1)***. Since duplicate samples were only separated during subsampling after incubation, the likely cause of this inconsistency was the incomplete homogenisation of cores before subsampling. The effect was worse for ammonium, presumably due to localised production of ammonium in anaerobic microsites together with lower rates of diffusion for ammonium ions than for the more weakly-adsorbed nitrate ions.

Figure 5.1: Consistency of ammonium and nitrate analyses between duplicate subsamples.



Analyses of reference samples showed some variation between batches, but there was no evidence of systematic bias (***Fig. 5.2***). The coefficient of variation (c.v.) for nitrate was somewhat greater for the low-N BS2 standard (15%) than for the high-N BS1 standard (9%). The c.v. for ammonium was similar (12%) for the low-N and high-N standards.

Figure 5.2: Nitrate (a & c) and ammonium (b & d) contents in high-N (BS1; a & b) and low-N (BS2; c & d) reference soils included with sample batches during CS in 2007 mineralisable N analyses.



Taken overall the QC data suggest that nitrate-N and total mineral N are more consistent than ammonium-N.

5.2.4 Reporting

Soil mineralisable N data have been analysed to provide information on the state of mineralisable N in 2007. The data in this Report describe mineralisable N concentration in 2007 in dry soil and in soil organic matter, mineralisable N stock (i.e. amount per hectare), and nitrate proportion of mineralisable N (all measured in soil from 0-15 cm depth), categorised by Broad Habitat, Aggregate Vegetation Class (AVC) and soil type (LOI class). Concentrations in organic matter were obtained using the primary loss-on-ignition value recorded for the plot in 2007, i.e. from a core taken adjacent to the core used for mineralisable N analyses. In summary reporting categories are defined as:

- Broad Habitat - The Broad Habitat classification consists of 27 habitats which account for the entire land surface of Great Britain, and the surrounding sea. Countryside Survey reports on soils for 10 major terrestrial habitats.
- Aggregate Vegetation Class (AVC) – is a high level grouping of vegetation types produced from a quantitative hierarchical classification of the different plant species found in the original Countryside Survey sample plots.
- Loss on ignition (LOI) category – soil type based on soil organic matter content defined as mineral (0-8% LOI; 0-44 g C kg^{-1}), humus-mineral (8 – 30% LOI ; 44-165 g C kg^{-1}), organo-mineral (30 – 60% LOI; 165-330 g C kg^{-1}) and organic (60 – 100%; > 330 g C kg^{-1}).

Mineralisable N was not measured in previous surveys, so no results regarding change can be presented. Log-transformed data were analysed by REML using the mixed models procedure of SAS (SAS Institute 2006). Back-transformed means and standard errors are presented. Significant results relate to statistical significance with their ecological and policy relevance highlighted where appropriate. More details can be found in Emmett *et al.* (2008), Annex F.

The data for mineralisable N concentration in soil and in organic matter, and for nitrate proportions, were mapped using kriging to interpolate between the Countryside Survey sample points. Routine checking of data for outliers was conducted and the working dataset was transformed using a normal score procedure to obtain a Gaussian distribution. The data were then interpolated on a 1km UK grid using ordinary kriging and finally, the kriged data were back-transformed to produce interpolated maps. In addition, sequential Gaussian simulation (SGs) was conducted on the data to obtain the E-type estimate (mean) and the spatial uncertainty for the data (conditional variance). The coefficient of variation, CV, (standard deviation / mean) is reported.

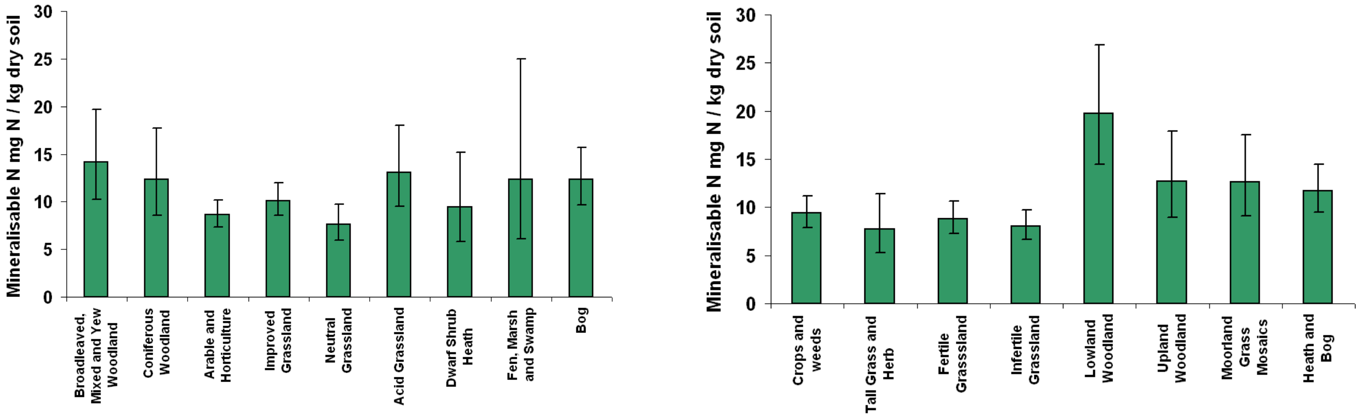
5.3 Results

5.3.1 Total mineralisable N concentration in soil

The log-average concentration of mineralisable N measured across all British soils was 10.2 mg N / kg dry soil. The distributions of mineralisable N concentration by Broad Habitat, AVC and LOI class are shown in ***Fig. 5.3***. The greatest concentrations were found in the Lowland Woodland AVC, and the aggregation by Broad Habitat suggests that concentrations were high in both Coniferous and Broadleaf/Mixed/Yew Woodland. Similar concentrations were found in the Fertile Grassland and Infertile Grassland AVCs, but the greater disaggregation in the Broad Habitat data allows a difference between infertile grassland types to be distinguished, with lower concentrations of mineralisable N in Neutral Grassland than in Acid Grassland ($P < 0.05$). There was a clear increase in mineralisable N concentration with the organic matter content of the soil, as illustrated by the differences in mean concentration among loss-on-ignition classes.

Mean mineralisable N concentrations across all habitat types were not significantly different among England, Scotland and Wales. Where more than 20 mineralisable N analyses were available for a Broad Habitat within a country, mean concentrations were derived (**Table 5.2**). Comparisons across countries are only possible for a limited set of Broad Habitats. Mineralisable N concentrations were similar ($P > 0.05$) in England and Scotland for Arable and Horticulture, and for Neutral Grassland. Concentrations in Improved Grassland were similar in all three countries.

Figure 5.3: Mean (+/- one standard error) mineralisable nitrogen concentration (mg per kg dry soil) in soil (0-15 cm depth) within: a) Broad Habitats; b) Aggregate Vegetation Classes; and c) Soil Loss-on-ignition categories, across Britain. Analyses were on log-transformed data; means and error bars back-transformed to the original scale.



a) Broad Habitats

b) Aggregate Vegetation Classes

c) LOI categories

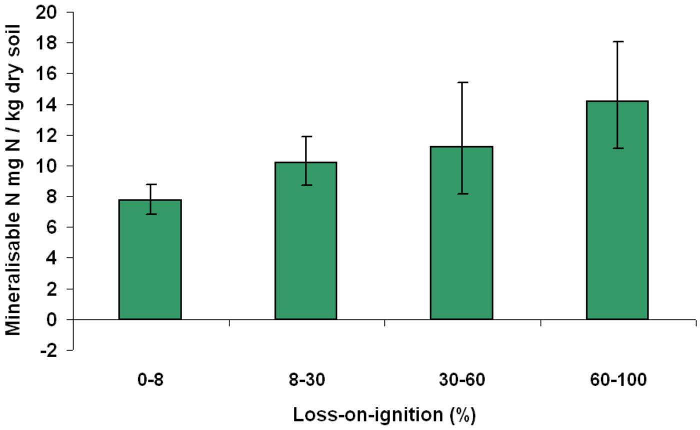


Table 5.2: Mineralisable N concentrations (mg N / kg dry soil) in soils (0-15 cm depth) across all habitats, and in selected Broad Habitats, in England, Scotland and Wales.

a) England

Broad Habitat	Mean total mineralisable N (mg N / kg dry soil) 2007
Broadleaved, Mixed and Yew Woodland	16.0
Arable and Horticulture	8.3
Improved Grassland	10.1
Neutral Grassland	6.9
All habitat types	9.8

b) Scotland

Broad Habitat	Mean total mineralisable N (mg N / kg dry soil) 2007
Coniferous Woodland	12.7
Arable and Horticulture	10.8
Improved Grassland	10.1
Neutral Grassland	8.5
Acid Grassland	11.3
Dwarf Shrub Heath	7.6
Bog	11.5
All habitat types	10.4

c) Wales

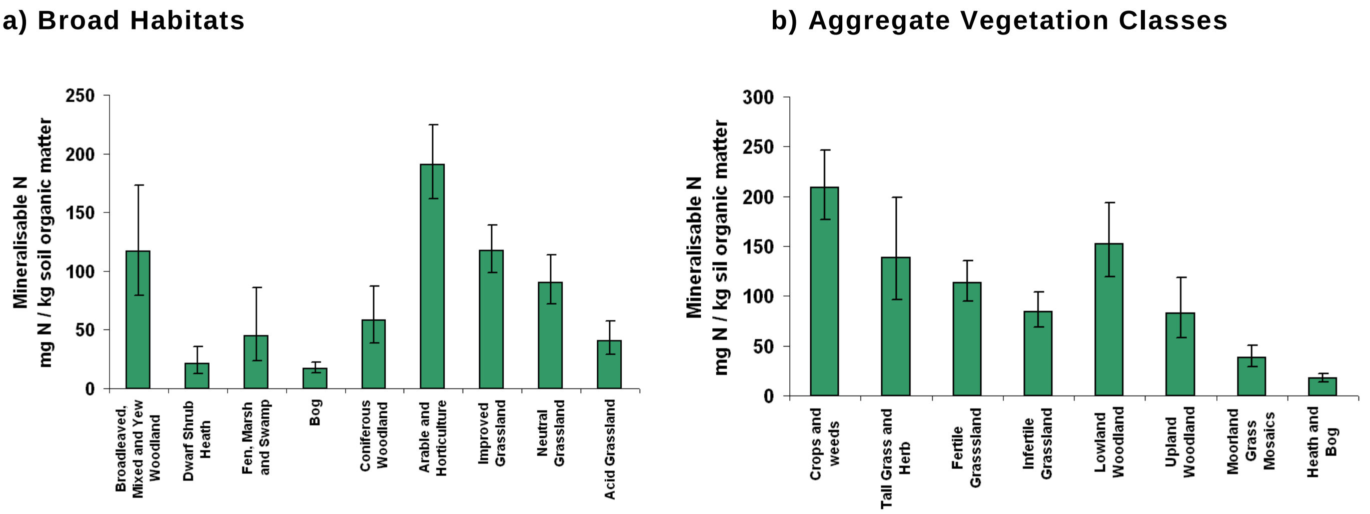
Broad Habitat	Mean total mineralisable N (mg N / kg dry soil) 2007
Improved Grassland	10.0
All habitat types	11.2

5.3.2 *Total mineralisable N concentration in soil organic matter*

The log-average concentration of mineralisable N in organic matter measured across all British soils was 76 mg N / kg loss-on-ignition. The distributions of mineralisable N concentration in soil organic matter by Broad Habitat, Aggregate Vegetation Class and soil loss-on-ignition class are shown in ***Figure 5.4***. Differences in mineralisable N concentration in organic matter among Broad Habitats, Aggregate Vegetation Classes and loss-on-ignition categories are clearly distinguishable compared with differences in concentrations in soil ***(Fig. 5.4)****.* Mineralisable N concentration in organic matter was greater in habitats with fertiliser inputs and/or fast litter turnover (e.g. Broadleaved, Mixed and Yew Woodland, and Arable and Horticulture Broad Habitats; or Lowland Woodland, and Crops and Weeds AVCs) than in habitats receiving little or no fertiliser input and with impeded litter turnover (e.g. Dwarf Shrub Heath, and Bog Broad Habitats; or the Heath and Bog AVC).

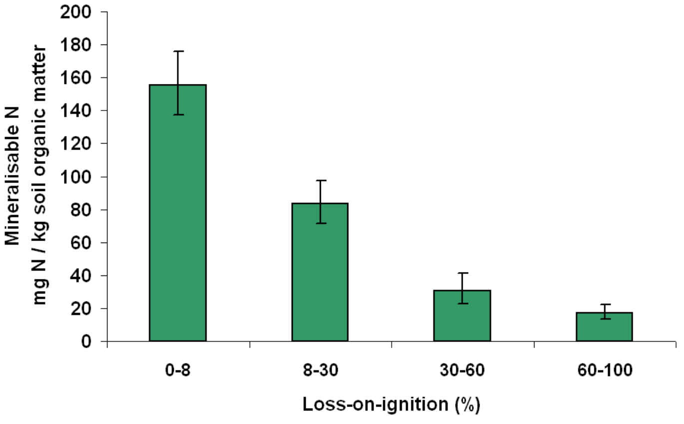
This measurement distinguished mineralisable N concentrations in organic matter in different grassland AVCs, with greater concentrations in Fertile Grassland than in Infertile Grassland. In contrast to concentration in dry soil, the Neutral Grassland Broad Habitat had greater concentrations of mineralisable N in organic matter than did Acid Grassland ($P < 0.01$). Concentrations in organic matter in Neutral Grassland and Improved Grassland Broad Habitats were similar ($P > 0.01$).

Figure 5.4: Mean (+/- one standard error) mineralisable nitrogen concentration in soil organic matter (mg N / kg loss-on-ignition) in soils (0-15 cm depth) within: a) Broad Habitats; b) Aggregate Vegetation Classes; and c) Soil Loss-on-ignition categories, across Britain. Analyses were on log-transformed data; means and error bars back-transformed to the original scale.


a) Broad Habitats

b) Aggregate Vegetation Classes

c) LOI categories



Mean mineralisable N concentrations in organic matter across all habitat types were lower in Wales than in England (*P* < 0.05) and lower in Scotland than in Wales (*P* < 0.05). Where more than 20 mineralisable N analyses were available for a Broad Habitat within a country, mean concentrations were derived **(Table 5.3).** Comparisons across countries are only possible for a limited set of Broad Habitats. As with concentrations in soil, mineralisable N concentrations in organic matter were similar (*P* > 0.05) in England and Scotland for Arable and Horticulture, and for Neutral Grassland, and concentrations in Improved Grassland were similar (*P* > 0.05) in all three countries.

Table 5.3: Mineralisable N concentrations in soil organic matter (mg / kg loss-on-ignition) in soils (0-15 cm depth) across all habitats, and in selected Broad Habitats, in England, Scotland and Wales.

a) England	
	Mean total mineralisable N (mg N / kg loss-on-ignition)
Broad Habitat	2007
Broadleaved, Mixed and Yew Woodland	149.1
Arable and Horticulture	189.3
Improved Grassland	118.1
Neutral Grassland	86.0
All habitat types	126.5

b) Scotland	
	Mean total mineralisable N (mg N / kg loss-on-ignition)
Broad Habitat	2007
Dwarf Shrub Heath	15.6
Bog	16.0
Coniferous Woodland	58.0
Arable and Horticulture	197.4
Improved Grassland	121.4
Neutral Grassland	100.7
Acid Grassland	27.5
All habitat types	41.2

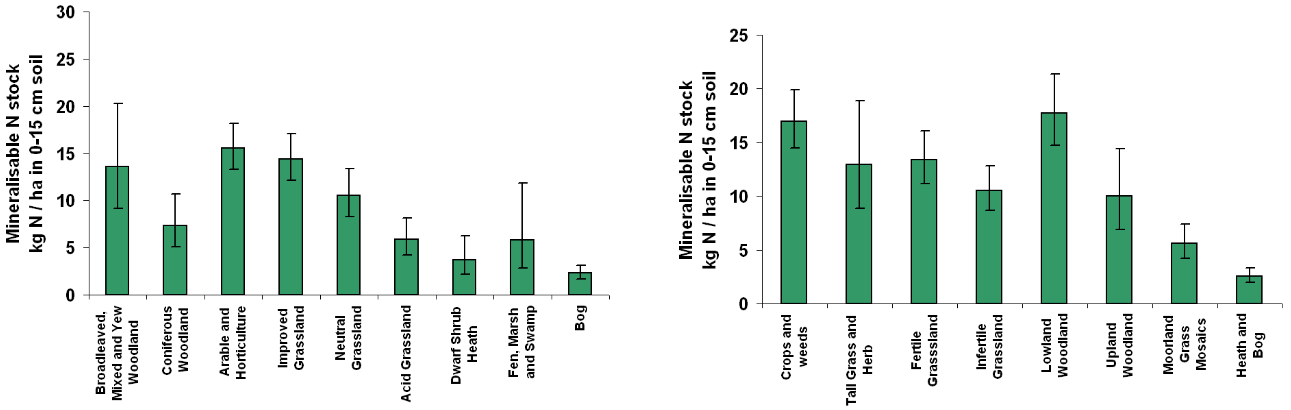
c) Wales	
	Mean total mineralisable N (mg N / kg loss-on-ignition)
Broad Habitat	2007
Improved Grassland	110.5
All habitat types	91.4

5.3.3 *Total mineralisable N stock*

The log-average mineralisable N stock measured across all British soils was 8.8 kg ha^{-1} in 0-15 cm depth soil. The distributions mineralisable N stock by Broad Habitat, Aggregate Vegetation Class and soil loss-on-ignition class are shown in ***Figure 5.5***.

The measurement distinguished soils and habitats that are considered fertile from those considered infertile more clearly than mineralisable N concentrations in soil, and arguably more clearly than mineralisable N concentrations in soil organic matter. Broad Habitats such as Arable and Horticulture and Improved Grassland had consistently large mineralisable N stocks, and Bog and Dwarf Shrub Heath had consistently large stocks, but the stocks in Fen, Marsh and Swamp Broad Habitats were more variable. Coniferous and Broadleaf, Mixed and Yew Woodland Broad Habitats had similar mineralisable N stocks, but the Lowland Woodland AVC had significantly greater stocks than the Upland Woodland AVC. Mineralisable N stocks were similar in the 0-8 % and 8-30 % loss-on-ignition categories, but smaller in the 30-60 % loss-on-ignition category (P < 0.05), and still smaller in the 60-100 % loss-on-ignition category (P < 0.05).

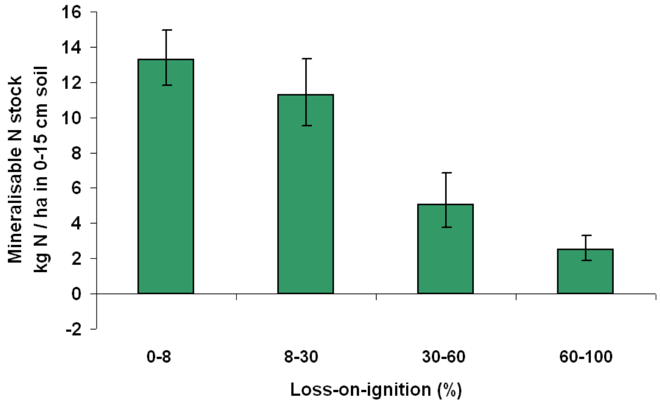
Figure 5.5: Mean (+/- one standard error) stock of total mineralisable nitrogen (kg N ha-1) in the top 15 cm of soil, within: a) Broad Habitats; b) Aggregate Vegetation Classes; and c) Soil Loss-on-ignition categories, across Britain.



a) Broad Habitats

b) Aggregate Vegetation Classes

c) LOI categories



Mean mineralisable N stocks in 0-15 cm depth soil across all habitat types were lower in Scotland than in England or Wales (*P* < 0.05). Where more than 20 mineralisable N analyses were available for a Broad Habitat within a country, mean concentrations were derived (***Table 5.4***). As with concentrations in soil and in soil organic matter, mineralisable N stocks were similar ($P > 0.05$) in England and Scotland for Arable and Horticulture, and for Neutral Grassland, and stocks in Improved Grassland were similar ($P > 0.05$) in all three countries.

Table 5.4: Mean (+/- one standard error) stock of total mineralisable nitrogen (kg N ha-1) in the top 15 cm of soil, across all habitats, and in selected Broad Habitats, in England, Scotland and Wales.

a) England	
	Mean total mineralisable N stock (kg N / ha in 0-15 cm soil)
Broad Habitat	2007
Broadleaved, Mixed and Yew Woodland	18.7
Arable and Horticulture	15.3
Improved Grassland	14.6
Neutral Grassland	10.1
All habitat types	13.7

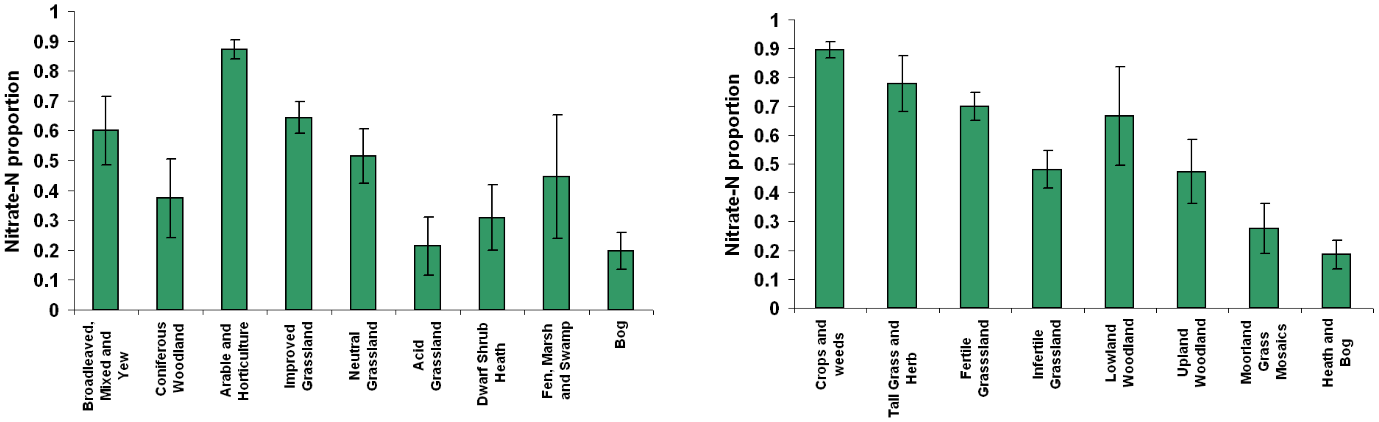
b) Scotland	
	Mean total mineralisable N stock (kg N / ha in 0-15 cm soil)
Broad Habitat	2007
Coniferous Woodland	7.2
Arable and Horticulture	17.2
Improved Grassland	14.3
Neutral Grassland	11.1
Acid Grassland	3.9
Dwarf Shrub Heath	2.6
Bog	2.2
All habitat types	5.2

c) Wales	
	Mean total mineralisable N stock (kg N / ha in 0-15 cm soil)
Broad Habitat	2007
Improved Grassland	14.0
All habitat types	11.4

5.3.4 Nitrate proportion of mineralisable N

The mean proportion of nitrate in total mineralisable N measured across all British soils was 0.52 g NO_3-N g^{-1} total mineralisable N, and there was considerable variation in nitrate proportion among Broad Habitats, Aggregate Vegetation Classes and soil loss-on-ignition classes (***Fig. 5.6***). There was no overall correlation of nitrate proportion with mineral N concentration in soil ($P > 0.05$), but nitrate proportion was correlated with mineral N concentration in soil organic matter ($c = 0.39$; $P < 0.05$). The pattern of mean nitrate proportion among vegetation and soil classes was similar to the pattern of mineral N concentration in soil organic matter, with the greatest proportions of nitrate in the Arable and Horticulture Broad Habitat and the Crops and Weeds AVC, and small nitrate proportions in less fertile habitats such as Bog, Acid Grassland and Dwarf Shrub Heath. The nitrate proportion could also be clearly related to soil organic matter content, with the lowest nitrate proportion in the soil category with greatest loss-on-ignition.

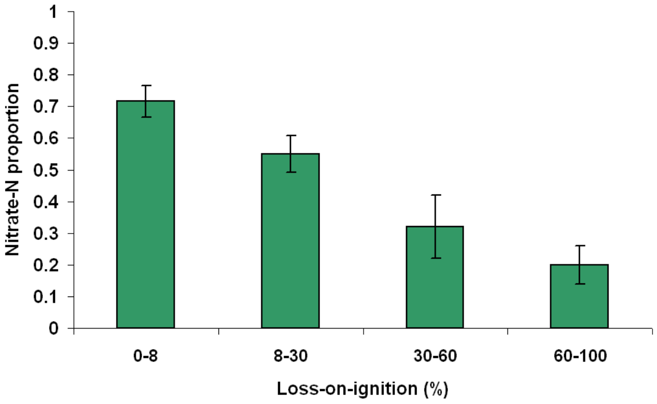
Figure 5.6: Mean (+/- one standard error) nitrate proportion of total mineralisable nitrogen, in soils (0-15 cm depth) within: a) Broad Habitats; b) Aggregate Vegetation Classes; and c) Soil Loss-on-ignition categories, across Britain.



a) Broad Habitats

b) Aggregate Vegetation Classes

c) LOI categories



Mean nitrate proportions across all habitat types were similar in England and Wales ($P > 0.05$) and lower in Scotland than in either country ($P < 0.05$) (***Table 5.5***). Where more than 20 mineralisable N analyses were available for a Broad Habitat within a country, mean concentrations were derived. Comparisons across countries are only possible for a limited set of Broad Habitats. As with total mineralisable N concentrations in soil and in organic matter, nitrate proportions were similar ($P > 0.05$) in England and Scotland for Arable and Horticulture, and for Neutral Grassland, and nitrate proportions in Improved Grassland were similar ($P > 0.05$) in all three countries.

Table 5.5: Nitrate proportion of total mineralisable nitrogen in soils (0-15 cm depth) across all habitats, and in selected Broad Habitats, in England, Scotland and Wales.

a) England	
	Mean nitrate proportion of mineralisable N
Broad Habitat	2007
Broadleaved, Mixed and Yew Woodland	0.67
Arable and Horticulture	0.87
Improved Grassland	0.68
Neutral Grassland	0.54
All habitat types	0.69

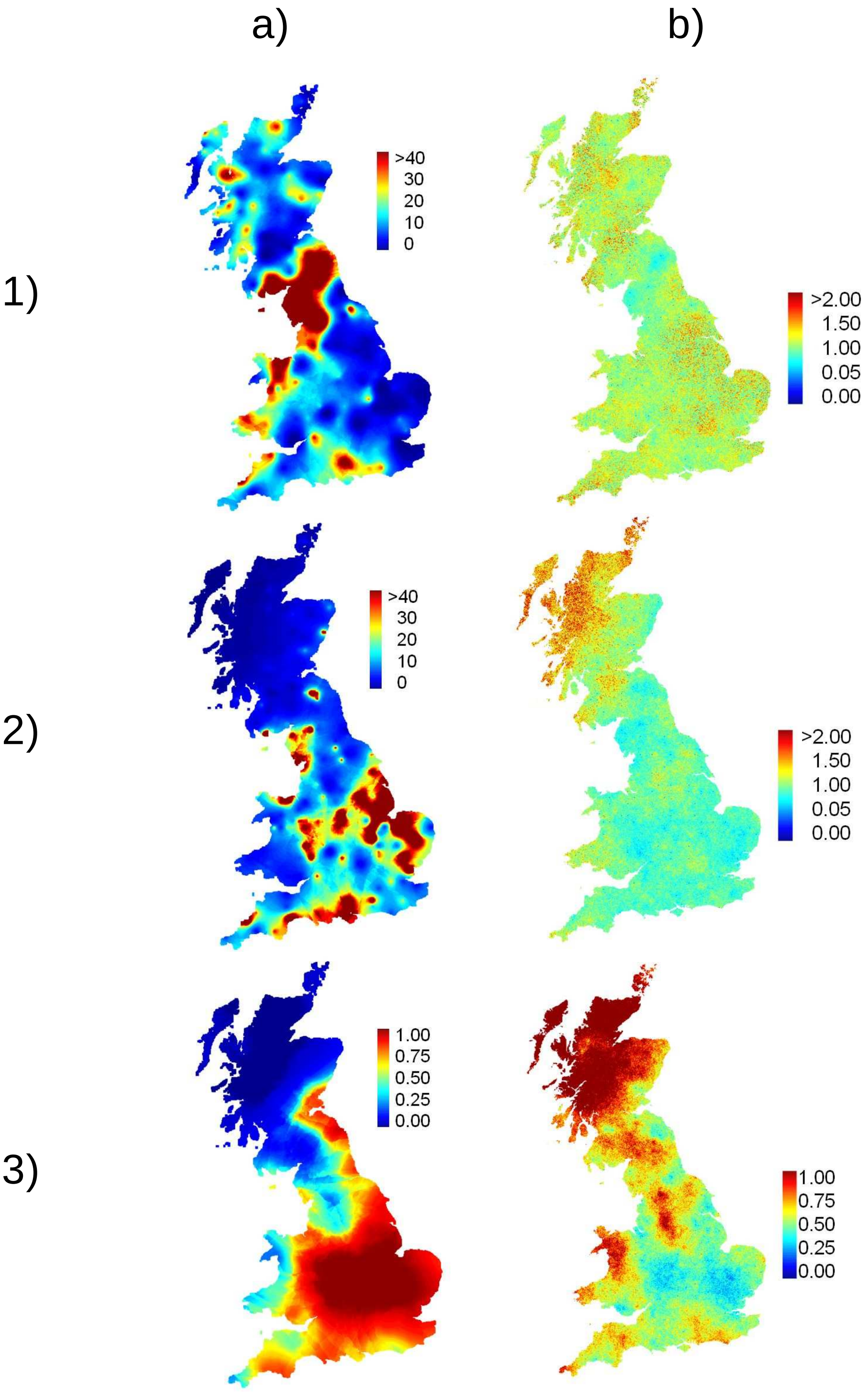
b) Scotland	
	Mean nitrate proportion of mineralisable N
Broad Habitat	2007
Coniferous Woodland	0.30
Arable and Horticulture	0.88
Improved Grassland	0.60
Neutral Grassland	0.50
Acid Grassland	0.11
Dwarf Shrub Heath	0.31
Bog	0.19
All habitat types	0.37

c) Wales	
	Mean nitrate proportion of mineralisable N
Broad Habitat	2007
Improved Grassland	0.57
All habitat types	0.57

5.3.5 Spatial distributions of measured properties

High concentrations of mineralisable N in soil were found in several areas of Britain **(*Fig. 5.7.1a & b*).** This pattern is difficult to interpret, but is perhaps due to the combined effects of greater organic matter contents in some areas (and hence a greater total N pool, some of which is available for mineralisation) and a history of greater N deposition in the same or other areas. By contrast, high concentrations of mineralisable N in organic matter ***(Fig. 5.7.2a & b)*** appear more related to management practices and concentrations of N deposition, in particular in areas with more mineral soils. There was less small-scale variation in the proportion of nitrate in mineralisable N ***(Fig. 5.7.3a & b)***, with low proportions in the north and west of Scotland and greater proportions in eastern Britain, in particular in central England suggesting links to spatial drivers at large scale, such as soil moisture deficit, soil pH and/or N fertiliser application rate.

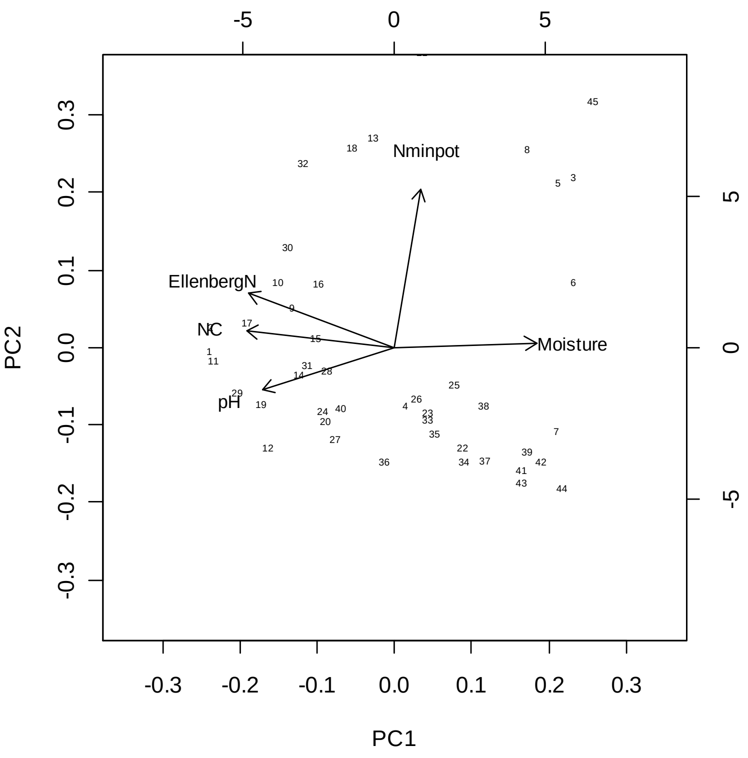
Figure 5.7. Maps of a) kriged values and b) coefficients of variation for: 1) total mineralisable N (mg N kg^{-1} soil); 2) total mineralisable N concentration in organic matter (mg N kg^{-1} loss-on-ignition); and 3) nitrate proportion of total mineralisable N.



5.3.6 *Mineralisable N as an indicator of floristic change*

To assess the effectiveness of mineralisable N data as an indicator of eutrophication it will be necessary to analyse the data in relation to other soil measurements and species occurrence data, which is beyond the scope of this report. Some results are presented here from a pilot study conducted in 2006 as a trial of the mineralisable N method for CS in 2007. All UK plant species have been assigned “Ellenberg N” scores which indicate whether they are likely to occur on high- or low-fertility sites. A key test of potential soil indicators of eutrophication is whether they are associated with mean Ellenberg N score. A PCA plot of results from the pilot study ***(Fig. 5.8)*** demonstrates clearly that mean Ellenberg N is most closely associated with bulk soil properties – for example, the vector for Ellenberg N has a small angle with N/C ratio. The position of the N/C ratio vector opposite that for moisture shows that these are strongly but inversely related. This reflects the overall tendency for low-fertility plant communities to occur on organic soils with low N/C ratios and high moisture contents. The explanatory power of mineralisable N is also considerable, as shown by the length of this vector; and its position shows that the variation explained by mineralisable N is orthogonal to that explained by total soil N/C. In other words, mineralisable N describes variation in mean Ellenberg N that is not explained by bulk soil properties, implying that it is detecting a shorter-term enrichment signal or different soil or vegetation types. This is borne out by the considerable increase in proportion of the variance in Ellenberg N that is explained by moving from a regression model using only moisture content (R^2 = 50%) to a model using both moisture content and mineralisable N (R^2 = 70%) (Rowe *et al.*, in prep; Emmett *et al.* 2008).

Figure 5.8. Ordination of measurements from the Countryside Survey pilot study in 2006 on first and second principal components of the variation. EllenbergN = mean fertility indicator score for plant species present; Nminpot = total N mineralised during a four-week incubation; NC = total soil N / total soil C; pH = soil pH in water; Moisture = g water g^{-1} fresh soil.



5.4 Discussion

Net N mineralisation and nitrification result directly in increased exposure of plants to N and increased N leaching, so the mineralisable N results are indicators of N pollution *pressure*, in the sense of a direct cause of loss of biodiversity and of water quality. The results also provide indicators of the *state* of the soil ecosystem, in that net N mineralisation is likely to increase as the capacity of the soil organic matter pool to buffer N pollution is depleted. These indicators will be useful to discriminate which components of the loss of biodiversity and water quality are due to N pollution. The results will also be used to improve understanding of soil and vegetation processes in particular habitats, and improve models of water quality and biodiversity change. Measurements at a single point in time do not allow direct assessments of change in mineralisable N or nitrate proportion, but a repetition of the measurements would provide evidence for increased damage, or recovery, from N pollution. The measurements also enable some assessment of nutrient cycling in different ecosystems as required for the National Ecosystem Assessment. It should be noted that an increase in mineralisable-N would be considered a negative indicator for semi-natural ecosystems and a positive indicator for intensively managed productive systems.

The different measurements included in CS in 2007 allow a choice of the variable used to express mineralisable N. Total mineralisable N concentrations in soil are related to the quantity of the substrate, so mineralisable N concentration in soil is most clearly related to organic matter content ***(Fig. 5.3)***. The high mineralisable N concentrations in soil in the Lowland Woodland AVC may be explained in that Lowland Woodland tends to occur on mineral soils, but could also be the result of increased interception of N pollutants by woodland, or alternatively a greater proportion of labile N in woodland plant litter.

Mineralisable N concentration in organic matter is more directly relevant to underlying processes, since the N available per unit carbon reflects the value of the organic matter as a source of N for decomposers. Indeed this variable appears to more clearly reflect the overall fertility of habitats, with large concentrations in the Arable and Horticulture and Improved Grassland Broad Habitats as well as in Broadleaved, Mixed and Yew Woodland. This reflects the improved quality of the soil organic matter due to fertilisation, tillage and presence of crops with high litter quality and confirms the sensitivity of the assay to known differences in soil nitrogen availability for plants. In contrast to mineralisable N concentration in soil, there was a clear lower concentration in organic matter on more organic soils, which reflects the known increase in N limitation as soils become more organic. Thus whilst Broad Habitats such as Bog and Dwarf Shrub Heath are associated with high soil organic matter contents, they are generally N-limited as this organic matter contains relatively little net mineralisable N.

The stock of mineralisable N (i.e. the amount in a given volume of soil) also clearly reflected the overall fertility of habitats. Unlike concentrations in soil or in soil organic matter, which are more relevant for mineral and organic soils, respectively, stock is a measure of mineralisable N within a consistent soil volume. This reflects N availability within the rooting zone, and so more closely represents plant-available N across a variety of habitats.

To establish evidence of change in mineralisable N and thus of deposition-driven changes in soil processes likely to affect plant species composition, it will be necessary to analyse these data in combination with a range of external datasets such as pollutant load, grazing pressure, climate drivers which may affect the spatial trends observed. This work is ongoing and will be reported in the CS Integrated Assessment report later in 2010.

The proportion of nitrate in mineralisable N is known to be affected by aeration during the incubation. The texture of the soil on fine scales (e.g. clay, silt and sand fractions, or degree of humification of organic matter) and medium scales (e.g. porosity and aggregation) will affect the diffusion of air into the soil core. Both organic and mineral soils can vary considerably in porosity, and hence the increase in nitrate proportion with decreasing organic matter content cannot be clearly related to soil texture effects. Nitrification rates may also indicate the size of the nitrifying bacteria population, and hence greater nitrate proportions may be related to a history of elevated N inputs. The clear spatial effect on nitrate proportion ***(Fig. 5.6)*** implies that large scale drivers affect nitrate proportion more than soil texture, which varies at a smaller scale. These large scale drivers may include climate, pollutant load, soil pH and N fertiliser application rate, which all vary from NW to SE Britain in ways that are consistent with the spatial pattern of nitrate proportion. Further analyses of nitrate proportion in relation to site-specific total N deposition history, loads of pollutant and fertiliser NO_x and NH_y, and soil and habitat properties will provide more insights into the processes governing nitrate proportion and will be reported in the Integrated Assessment. These analyses will also inform whether nitrate proportion is of value as a *pressure* or *state* indicator.

As well as aiding the development of understanding and models of biogeochemical processes, the mineralisable N results will be useful to explain patterns of floristic change. Results from the CS in 2007 pilot study indicate that mineralisable N explains changes in plant species composition (specifically, mean Ellenberg N score) that cannot be explained by bulk soil properties such as total N or C/N ratio ***(Fig. 5.7)***. This will considerably reduce uncertainty in model chains used by the UNECE-CCE to predict floristic change resulting from N deposition. The result is consistent with the understanding from soil process ecology that a large and habitat-specific fraction of the soil N pool is effectively inert, with plant N supply being governed by the turnover of the more labile organic matter pools. The nitrate proportion in mineralisable N may also be a useful predictor of floristic change (Diekmann and Falkengren-Grerup 1998), for example because plants typical of lower-fertility habitats are not adapted for nitrate uptake.

In conclusion, the new measurements of mineralisable N provide a wealth of information useful for developing science and policy around the ecosystem impacts of N pollution. The measurements define a fraction of the soil N pool that is available to be taken up by plants efficiently and/or leached, and thus provide a sensitive indicator of N pollution and ecosystem saturation. Soils buffer N pollution, particularly when C/N ratios are high and there are large stocks of labile C, so N pollutant loads cannot be directly related to impacts relevant to water quality and biodiversity conservation objectives. The measurements will provide test data for biophysical models of soil change, and will also allow improved parameterisation of models predicting plant species occurrence and biodiversity change. Mineralisable N measurements will decrease uncertainty associated with linking these two classes of models, and thus improve predictions of biodiversity responses to N pollutant load. Future analyses will separate out the inherent variability associated with climate, vegetation and soil type to identify spatial patterns which can be linked to atmospheric deposition and changes in management.

5.5 Policy Implications

The new national scale mineralisable N measurements will allow:

- Separation of the effects of N pollution on biodiversity and water quality from effects of other drivers.
- Assessment of the relative impact of N deposition on different soils and habitats.
- Improved forecasts of changes in water quality and biodiversity in relation to N deposition rate, for use in calculating critical loads under the UNECE Convention on Long-Range Transboundary Air Pollution (CLRTAP).

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Summary

- **Mean Olsen-P concentrations in soil (0-15cm) is an index of the fertility of agricultural soils. It's use and relevance in semi-natural and organic soils is less certain. Soils collected during Countryside Survey in 1998 and 2007 indicated there had been a significant decrease in Olsen-P concentrations in soil (0-15cm) in most Broad Habitats or Aggregate Vegetation Classes across Great Britain and within individual countries.**
- **Olsen-P concentrations in soil (0-15cm) decreased significantly in all soil organic matter categories across Great Britain and within individual countries between 1998 and 2007 apart from humus-mineral soils in Scotland where no change was observed.**
- **The data do not confirm a trend of increasing P status in intensive grasslands or any other habitat soils (0-15cm) but indicate a loss of available phosphorus between 1998 and 2007 across a wide range of habitats and soil types. This is likely to be linked to the large reductions in phosphorus fertiliser use over the same period.**

6.1 Introduction

Key question: Can the trend of increasing P status in intensive grasslands be confirmed and is it matched in other habitats?

Measurements: Repeat measurement of Olsen-P concentrations in soils (0-15 cm) from all plots sampled in 1998.

Olsen-P (Olsen *et al.,* 1954) has been widely used in England and Wales to assess the fertility of agricultural soils (MAFF 2000). It was also measured as an integral part of several national soil monitoring schemes including the Representative Soil Sampling Scheme (RSSS; Archer *et al*., 2003), the National Soil Inventory (NSI; McGrath and Loveland 1992), the Environmental Change Network (ECN; Morecroft *et al.,* 2009) and the Soil Geochemical Atlas of Northern Ireland (Emmett *et al.,* 2008). Olsen-P has also been used in conjunction with the phosphorus sorption index to provide an index of the leaching risk of dissolved P from soils to freshwaters (Hughes *et al.,* 2001). In the UK, Olsen-P has been recommended as an indicator for environmental interactions between the soil and other linked ecosystems such as freshwaters (Black *et al.,* 2008).

Olsen-P was measured in soils taken from the 256 'soil squares' during *CS in 1998* but the samples were not analysed until 2002 or reported in the Monitoring and Assessing Soil Quality (MASQ) report (Black et al., 2000) although they are held on the CS database..The data were not included in the Defra funded study which examined the comparability of soil properties measured by different surveys and monitoring schemes where it was erroneously reported that total-P was measured in *CS in 1998* (Bradley *et al.,* 2003).

6.1.1 Choice of Olsen-P in 2007

A wide range of extractants have been used to measure the more soluble, weakly bound or 'available' forms of phosphorus in soils. Some of the more commonly used extractants include 1% citric acid, 2.5% acetic acid, dilute buffered sulphuric acid (Truog's reagent), acetic acid-sodium acetate buffer (Morgan's reagent) and sodium bicarbonate buffered at pH 8.5 (Olsen-P). There has been a long standing debate as to the most appropriate measure of soil available-P in relation to soil type. Olsen-P has been favoured for limed, fertilised agricultural soils and semi-natural ecosystems on base rich or circum-neutral soils whilst acid extractions are considered to be more appropriate for the more acidic soils found in many semi-natural and woodland ecosystems. Numerous studies have compared the performance of the different tests with each other, with plant response and with other factors (see e.g. Allen, 1989; Foy *et al.,* 1997 and discussion in Emmett *et al.,* 2008). The evidence so far from these and other studies reported in the literature suggests that it is unlikely that a simple, robust relationship can be established between Olsen-P and other extractants. A study comparing Olsen-P data from two different surveys, the Representative Soil Sampling Scheme (RSSS) and the National Soil Inventory (NSI), concluded that where the same analytical method had been used the data for phosphorus were entirely comparable (Bradley *et al.,* 2003).

The literature indicates that no one extractant is ideal for use across the range of soil fertility and pH gradients encountered in Countryside Survey. Thus, one option considered for CS in 2007 was to use more than one extractant with the choice being determined by the characteristics of each soil sample. For example, an acid extractant for semi-natural, acidic, low fertility soils and Olsen-P for more base-rich, fertile soils. This would have made the data very hard to interpret, particularly in relation to changes since CS in 1998 and for those soils with ‘intermediate’ characteristics where the choice of extractant was not clear. Furthermore, to maximise the use of pre-existing 1998 data, it would be hard to justify using another extractant, even though Olsen-P might not be ideal across the range of soil conditions encountered in Countryside Survey. Bearing these factors in mind, the decision was made to measure Olsen-P in 2007.

6.1.2 Deliverables for 2007

CS in 2007 has provided the following deliverables:

- **Whole GB and country-level assessment of soil available-P status in 2007**
- **GB-level assessment of change in soil available-P status between Countryside Survey in 1998 and Countryside Survey in 2007**
- **Explanatory data to contribute to the analysis of other Countryside Survey datasets such as those describing changes in vegetation species and the trophic status of freshwaters**

The Olsen-P data collected in 2007 can also contribute to the assessment of Broad and Priority Habitat condition in relation to soil fertility and the data will provide a baseline assessment for a recommended UK soil indicator. The rationale for including Olsen-P within the Countryside Survey measurement suite is summarised in ***Table 6.1***.

Table 6.1: Rationale for measurement Olsen-P

Issue	Facts	Comments
History in Countryside Survey	Olsen-P measured on samples from 256 squares in *CS in 1998*	Olsen-P used as a measure of available-P
Links and compatibility to other monitoring programmes	NSI and RSSS used Olsen-P as a measure of available-P to the same depth (0-15 cm) as Countryside Survey	Defra project SP0515 concluded that measurements were comparable between NSI and RSSS.
Uniqueness of CS	There was a partial resurvey of the NSI in 2003. RSSS has data reported to 2001. Soil pH was measured at many ECN sites in 1998 and 2003. Unique combination of soil, vegetation & land use measured together	High interpretative value for: i) terrestrial vegetation species change in response to fertility in combination with soil nitrogen ii) trophic status of linked freshwaters
Value for money (Policy priority or interpretative value X cost)	Recommended UK soil indicator for environmental interaction cheap, simple measurement; High value for money	Measurement will be made on ‘black core’ soil sample used for pH & LOI core measurements

So far, measures of soil available-P have not been included in models exploring the relationships between vegetation species change recorded in CS in 1998 and soil nitrogen enrichment through atmospheric nitrogen deposition. However, soil-P data are likely to have strong interpretative power in the analysis of model simulations and predictions.

6.2 Methods

The soil used for phosphorus analysis was taken from the 'black core' and there were no specific sampling requirements beyond those normally employed for collecting the 'black core' sample (See Chapter 1 & Emmett *et al.,* 2008, Annex 1).

A total of 1054 black cores were collected from the 5 Main Plots in the original 256 "soil" squares. Air-dried and sieved samples (<2 mm) were analysed for Olsen-P at CEH in Lancaster in the autumn of 2008 following the standard operating procedure (Emmett *et al.,* 2008). This involved extraction of 5 g of air-dried, sieved soil with 100 ml of 0.5M sodium bicarbonate at pH 8.5. The phosphorus in the extract was determined colorimetrically using a continuous flow analyser. The analyser method used molybdenum blue at 880nm with the addition of a dialysis step to overcome the effect of the Olsen's reagent.

Olsen-P is expressed in mgP/kg dry soil. Samples collected from 1998 were analysed in 2002 and those from 2007 in 2008.

6.2.1 Quality Assurance and Quality Control

The Defra/NERC/BBSRC Joint Codes of Practice were followed.

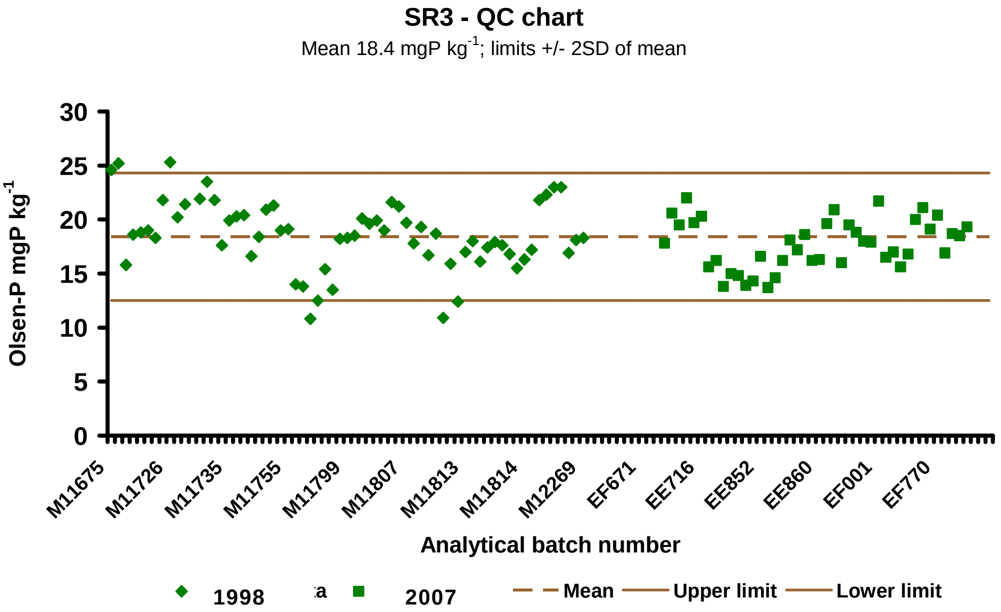
A number of factors can contribute to errors in the analysis of Olsen-P, and steps were taken to minimise potential artefacts:

- Effect of drying – drying soil affects the release of phosphorus with enhancements of up to 30% possible from drying at 40 ºC (Jackson 1958). The effect varies with soil type (Allen, 1989). If field moist soil is used, larger quantities are recommended for the extraction (10 g to 100 ml for mineral soil and up to 25 g to 100 ml for peats; Allen, 1989). Methodological consistency is very important. Since the Olsen-P measurements made on 1998 soils used air-dried soils, the same procedure was used in 2007.
- Extraction temperature – the extraction is temperature sensitive and must be performed under constant temperature conditions. Extraction procedure and conditions were matched to those used for the analysis of 1998 soils.
- Soil:solution ratio and extraction time – these may affect the amount of phosphorus extracted and a consistent method should be employed. The same standard operating procedure was used in 1998 and 2007.
- Effect of organic matter – the high pH of the Olsen-P extraction means that some organic matter is also extracted. Organic phosphorus is not measured by the molybenum blue method. The wavelength used for the molybdenum blue determination (880 nm) is a long way from any likely interference effects from extracted humic acids.

A replicate analysis, two standard reference soils and one certified reference soil were analysed per batch of 25 samples. The same standard reference soils were used in the analysis of samples from 1998 and 2007 providing a check on the consistency of the analyses between the two surveys.

The results from the standard reference soils are summarised in ***Fig. 6.1***, ***Fig. 6.2*** and ***Table 6.2***. For SR2 and SR3 the data show the expected variation around the mean value ***(Fig. 6.1)***. A simple t-test showed that the mean value of SR2 in 2008 (14.6 mgP/kg) was significantly higher ($p<0.001$) compared to the mean in 2002 (12.8 mgP/ kg); there was no significant difference between the mean values for SR3. Fewer values outside the limits on the Shewhart charts and smaller coefficients of variation ***(Table 6.2)*** indicate that the results for both standard reference soils were more consistent in 2008 compared to 2002.

Figure 6.1: Shewhart Quality Control charts for CEH standard reference soils SR2 and SR3 analysed with sample batches from *CS* in 1998 and 2007.



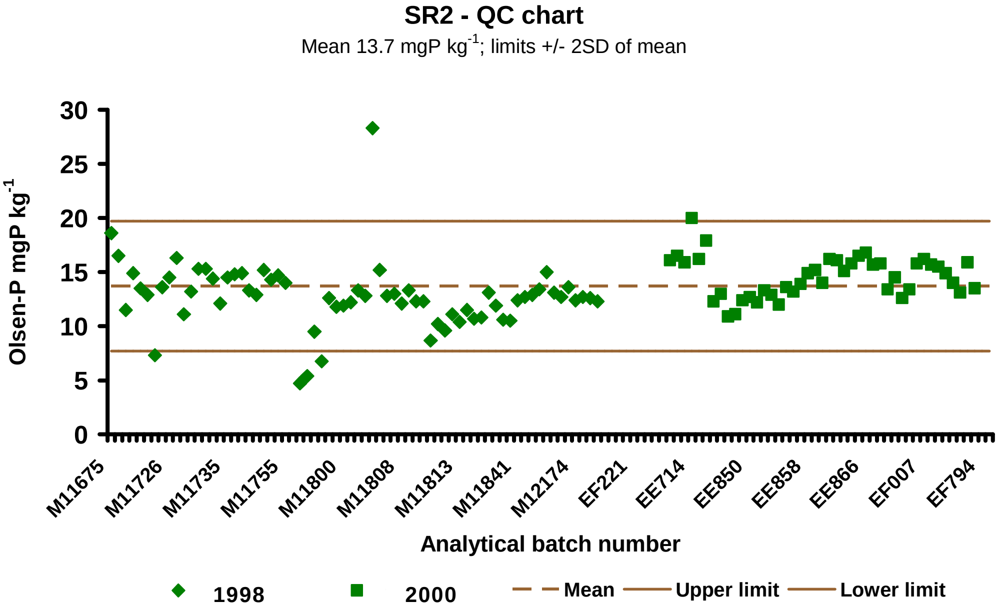
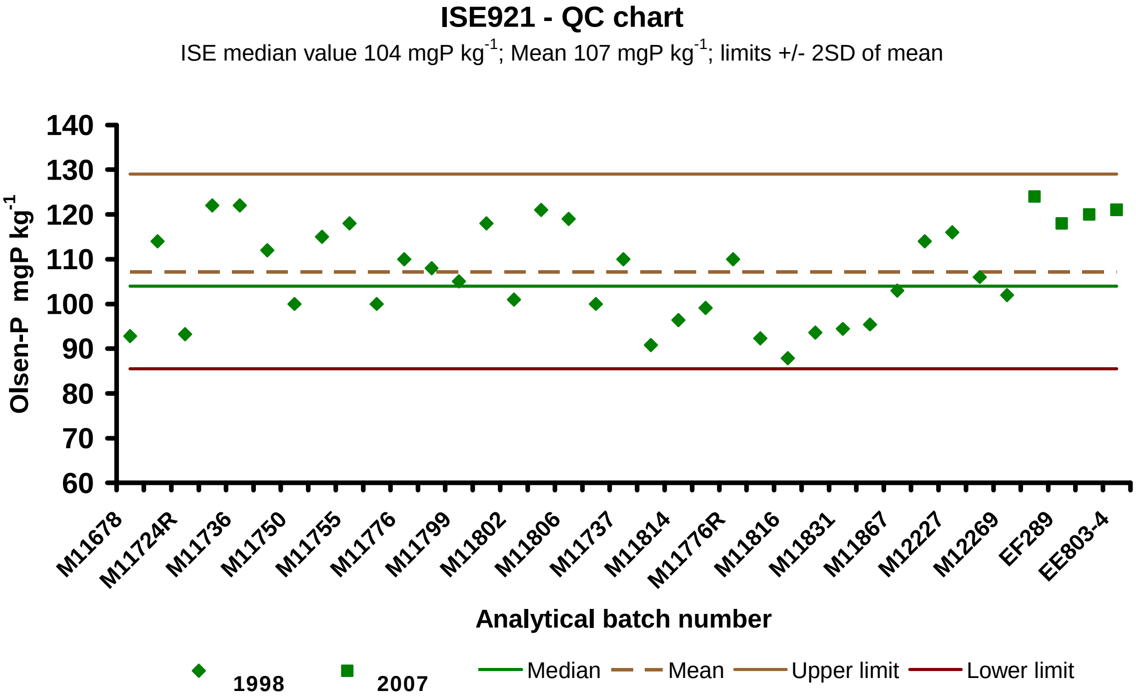


Table 6.2: Mean values (mgP/kg) and coefficients of variation (CV %) for the standard reference soils analysed with samples from CS in 1998 and 2007.

Standard reference soil	SR2	SR3	ISE921
Mean 1998 (CV%)	12.8 (24)	18.6 (17)	105.5 (10)
Mean 2007 (CV%)	14.6 (13)	17.7 (13)	120.8 (2)

The mean and median values for the standard reference soil ***(Fig. 6.2)*** are those obtained from data submitted by all the laboratories participating in the scheme. Unfortunately, there is a limited stock of this material at CEH Lancaster so that only four samples were analysed with the 2008 batches. The Shewhart chart ***(Fig. 6.2)*** shows some expected variation, but 84% of the points lie within the limit values. The four points at the end of the chart were produced during the 2008 analyses and are within the range of results obtained in 2002. The 2008 mean value is somewhat higher ***(Table 6.2)*** but as only four samples of ISE921 were analysed with the 2008 batches, this result must be interpreted with care.

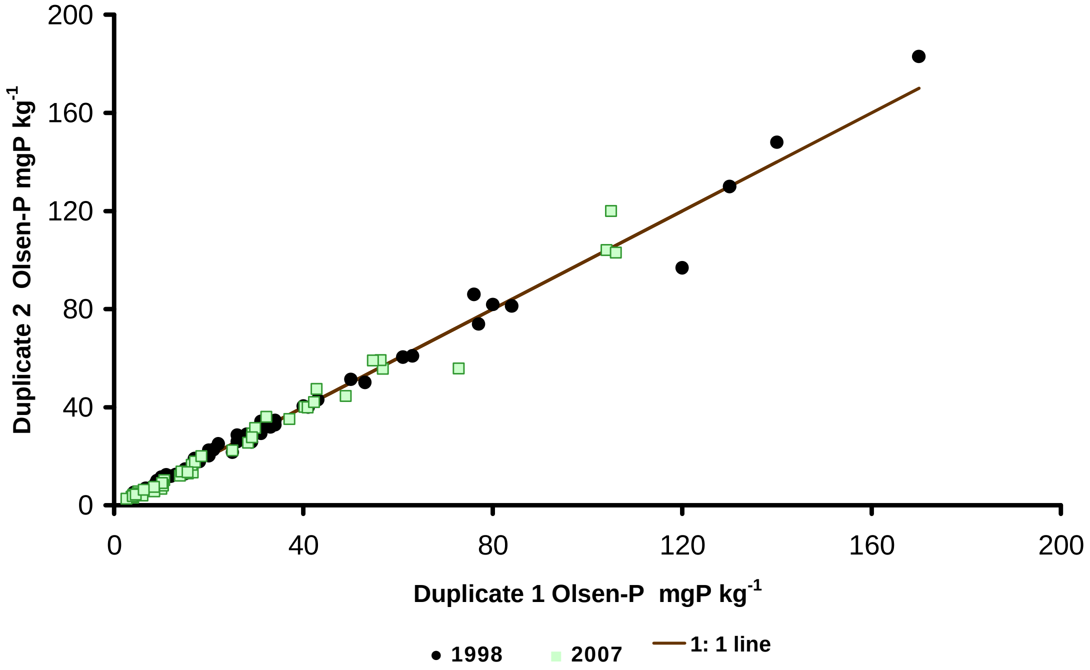
Figure 6.2: Shewhart QC chart for ISE standard reference soil ISE921 analysed with sample batches from CS in 1998 and Countryside Survey 2007.



The duplicate analyses undertaken within sample batches in 2002 and 2008 were very consistent with most points falling on or close to the 1:1 line ***(Fig. 6.3)***. The mean difference between duplicates was small in 2002 (-0.1 mgP/ g) and 2008 (0.6 mgP/kg). Differences between duplicates were larger for samples with high concentrations of Olsen-P.

Taken overall the Quality Control data show strong consistency within and between the measurements made in 2002 and 2008 and give little cause for concern regarding a comparison of Olsen-P data from 1998 and 2007. There is a suggestion that the results for the standard reference soils were more consistent in 2008 with higher mean values. The values obtained in 2008 generally fall within the range measured in 2002 and within acceptable limits on the Shewhart charts.

Figure 6.3: Scatter plot of duplicate Olsen-P analyses from sample batches analysed in 2002 and 2008.



6.2.2 Reporting

Soil Olsen-P data (0-15 cm) have been analysed to provide information on the state of Olsen-P in 2007 and the change since 1998. The statistical approach used for analysing the data for change involved bootstrapping which allows for non-normality in the data without the necessity of knowing details of the actual distribution. As such it provides a more accurate measurement of significance. Annex F of Emmett *et al.* (2008) provides a background document describing this approach.

The data in this report describe mean Olsen-P concentrations in soils (0-15 cm) in 2007 and change since 1998 by Broad Habitat, Aggregate Vegetation Class (AVC) and Loss-on-Ignition (LOI) category. LOI classes are defined as: mineral (0-44 g C kg^{-1}), humus-mineral (44-165 g C kg^{-1}), organo-mineral (165-330 g C kg^{-1}) and organic (> 330 g C kg^{-1}). To remove the effects of large-scale vegetation and / or land use change mean Olsen-P concentrations have also been estimated for plots where the AVC has not changed over time. The AVC is only known for the survey years and may change during intervening periods, for example due to arable-grassland rotation. The plots where the AVC has not changed can be regarded as plots where the vegetation has been largely consistent in 1978, 1998 and 2007.

The soil Olsen-P concentrations were mapped using indicator kriging to interpolate between the Countryside Survey sample points. The use of indicator kriging, rather than ordinary kriging and spatial interpolation, arises because of the type of data being analyzed. In the case of Olsen-P the assumption of connectivity between sample points with extreme values in space is not valid. For instance fertilizer applications in one location may have no spatial link to those in another. As a result, ordinary kriging, incorporating these extreme values provides erroneous interpolation, biased towards these extreme values. Indicator kriging provides a method of spatially interpreting the underlying patterns in the data without such a bias, interpolating the probability that the data falls above or below a given threshold. Semi-variogram analysis revealed a low level of spatial structure, strongest at the threshold level of 18mg/kg. Full indicator kriging was used to interpolate the probability of exceeding this threshold. A probability of 1 or above indicates that the data exceeds the specified threshold value at that location. Data was interpolated onto a 1 km UK grid.

6.3 Results

6.3.1 Structure of Olsen-P data

Olsen-P was measured in samples from 1068 plots in 2007, of which 65% were also sampled in 1998. Concentrations of Olsen-P measured in soils (0-15 cm) in 2007 ranged between 2 and 380 mgP/kg. Between 1998 and 2007, the proportion of samples containing 40 mgP/kg Olsen-P or less increased from 64% to 76%, whilst the proportion samples with greater than 80 mgP/kg decreased from 12% to 7.5%. Overall, there was evidence of a downward shift in Olsen-P concentrations across the entire range of values between 1998 and 2007 ***(Fig. 6.4)***. The population of values in 1998 and 2007 was highly skewed. There were no clear relationships between change in Olsen-P concentration and 2007 values for soil pH, LOI, moisture content, or change in soil pH and LOI between 1998 and 2007.

6.3.2. Change in mean Olsen-P concentration in soils (0-15cm) across Great Britain

The mean Olsen-P concentration in soil (0-15cm) across all Broad Habitat types in Great Britain decreased from 43 mgP/kg to 32 mgP/kg or by 26% between 1998 and 2007 ***(Table 6.3a)***. This change was evident in all individual Broad Habitats except Bracken ***(Fig. 6.5)***. The magnitude of change varied between Broad Habitats with the smallest significant decrease (11%) measured in Arable which also had the highest mean concentration of Olsen-P in 2007 (44 mgP/kg). The biggest percentage decrease between the surveys (58%) occurred in Dwarf Shrub Heath which also contained the highest mean concentration of Olsen-P (56 mgP/kg) in 1998. The lowest mean concentration of Olsen-P (13 mgP/kg), which did not change significantly between surveys, was measured in soils (0-15cm) beneath Bracken.

There was a significant decrease in mean Olsen-P concentration between 1998 and 2007 across all AVCs except for Lowland Woodland ***(Table 6.3b)***. The largest percentage decrease in mean values (51%) was observed in Moorland Grass Mosaics; Heath and Bog had the highest mean concentration of Olsen-P in 1998 (52 mgP/kg). Crops and Weeds showed the smallest percentage change between surveys in Olsen-P (11%); this AVC had the highest mean Olsen-P concentration in 2007 (44 mgP/kg).

Figure 6.4: Distribution of soil Olsen-P (0-15 cm) measurements a) Histogram for 1998 and 2007 b) Cumulative frequency for 1998 and 2007. Histogram frequencies normalised to percentage of total number of samples analysed in each survey.

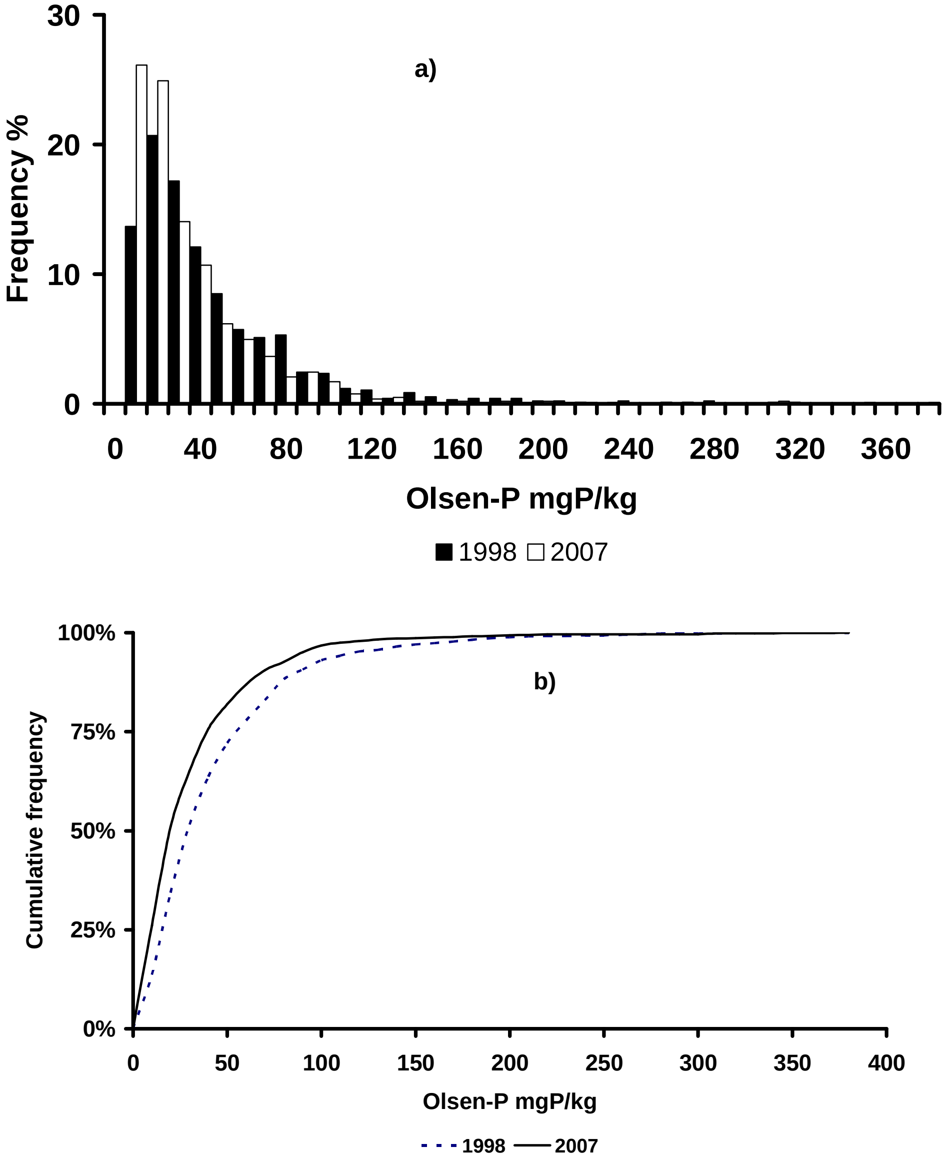


Table 6.3: Change in mean Olsen-P concentration of soils (0-15 cm) across Great Britain for a) Broad Habitats, b) Aggregate Vegetation Classes (AVC) c) AVCs unchanged since 1978 and d) LOI categories. Arrows denote a significant change (p<0.05) in the direction shown.

a) Great Britain - Broad Habitat			
Broad Habitats	Mean Olsen-P (mgP/kg)		Direction of significant changes
	1998	2007	1998 - 2007
Broadleaved, Mixed and Yew Woodland	40.4	23.8	↓
Coniferous Woodland	36.4	27.4	↓
Arable and Horticulture	49.6	44.2	↓
Improved Grassland	40.5	32.9	↓
Neutral Grassland	30.6	24.5	↓
Acid Grassland	46.4	21.1	↓
Bracken	17.3	13.0	
Dwarf Shrub Heath	56.0	23.6	↓
Fen, Marsh, Swamp	27.5	19.4	↓
Bog	53.3	38.4	↓
All Habitat Types	42.8	31.8	↓

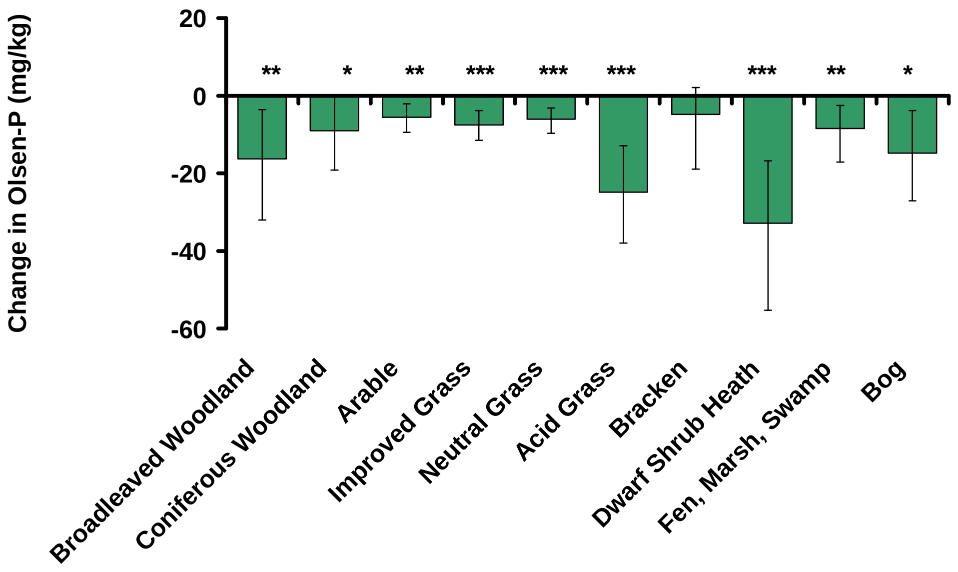
b) Great Britain – AVC whole dataset			
Aggregate Vegetation Class	Mean Olsen-P (mgP/kg)		Direction of significant changes
	1998	2007	1998 - 2007
Upland Woodland	29.6	18.2	↓
Lowland Woodland	24.7	29.5	
Fertile Grassland	42.6	33.5	↓
Infertile Grassland	30.1	21.0	↓
Moorland Grass Mosaic	49.5	24.2	↓
Heath and Bog	52.1	33.3	↓
Tall Grass and Herb	44.9	32.2	↓
Crops and Weeds	49.4	44.2	↓

) Great Britain – AVC unchanged			
Aggregate Vegetation Class	Mean Olsen-P (mgP/kg)		Direction of significant changes
	1998	2007	1998 - 2007
Upland Woodland	31.9	18.3	↓
Lowland Woodland	20.6	27.0	
Fertile Grassland	43.8	34.7	↓
Infertile Grassland	26.1	17.3	↓
Moorland Grass Mosaic	59.0	26.7	↓
Heath and Bog	47.1	31.8	↓
Tall Grass and Herb	42.4	29.4	
Crops and Weeds	49.9	43.8	↓

d) Great Britain – Loss on Ignition Category			
LOI Category (%)	Mean Olsen-P (mgP/kg)		Direction of significant changes
	1998	2007	1998 - 2007
Mineral (0-8)	40.5	33.9	↓
Humus-mineral (8-30)	32.9	24.1	↓
Organo-mineral (30-60)	40.9	19.4	↓
Organic (60-100)	63.0	44.1	↓

The mean Olsen-P concentrations in soils (0-15 cm) for plots in which the AVC did not change (***Table 6.3c)*** were broadly consistent with the dataset as a whole (***Table 6.3b***). The exception was Tall Grass and Herb, where no significant change in mean Olsen-P was observed for plots with consistent AVCs between surveys (***Table 6.4b***). This suggests that some of the change in Olsen-P observed for this AVC in the dataset as a whole may have arisen because of a change in land use between the surveys.

Figure 6.5: Change in mean Olsen-P concentration within Broad Habitats in Great Britain between 1998 and 2007.



Mean Olsen-P concentrations decreased significantly across all LOI categories ***(Table 6.3d)***, with the largest change observed in organo-mineral soils where mean Olsen-P declined by nearly 50%. In both surveys, the highest mean Olsen-P concentrations were observed in organic soils reflecting the high mean concentrations measured in Broad Habitats and AVCs with organic-rich soils (Dwarf Shrub Heath and Bog Broad Habitats, Moorland Grass Mosaic and Heath and Bog AVCs.

6.3.2. Change in mean Olsen-P concentration in soils (0-15cm) across England

Olsen-P was measured only on the Main Plots within the original 256 squares sampled in 1978, giving a maximum potential sample number of 1281 of which 1068 were sampled in 2007 and 943 in 1998. For this reason sample numbers decline rapidly in country-level data analysis. A minimum cut-off of 20 samples was applied for country-level analysis of Olsen-P by Broad Habitat, AVC and LOI Category. As a result, there are several gaps in the analysis; missing values in the tables are signified by a diagonal line across the cell.

There was a significant (16%) decrease in mean Olsen-P for the All Broad Habitats category in England between 1998 and 2007 ***(Table 6.4)***; this was the smallest overall change observed amongst the three countries. Arable soils (0-15 cm) contained the highest mean concentrations of Olsen-P in England 1998 (45.4 mgP/kg) and 2007 (41.8 mgP/kg), and there was a small (8%) but significant decrease between the two surveys. Mean Olsen-P concentrations in soils (0-15 cm) beneath Improved Grassland and Neutral Grassland in England were very similar in 2007 (≈ 26 mgP/kg) following significant decreases from levels observed in 1998 ***(Table 6.4)***.

Table 6.4: Change in mean Olsen-P concentration of soils (0-15 cm) across England for a) Broad Habitats, b) Aggregate Vegetation Classes (AVC) c) AVCs unchanged since 1978 and d) LOI categories. Arrows denote a significant change ($p<0.05$) in the direction shown. Diagonal line indicates too few samples to provide reliable value.

a) England - Broad Habitat			
Broad Habitats	Mean Olsen-P (mgP/kg)		Direction of significant changes
	1998	2007	1998 - 2007
Broadleaved, Mixed and Yew Woodland	33.8	26.9	
Coniferous Woodland			
Arable and Horticulture	45.4	41.8	↓
Improved Grassland	33.2	26.0	↓
Neutral Grassland	34.7	26.3	↓
Acid Grassland	41.2		
Bracken			
Dwarf Shrub Heath			
Fen, Marsh, Swamp			
Bog			
All Habitat Types	39.6	33.2	↓

b) England – AVC whole dataset			
Aggregate Vegetation Class	Mean Olsen-P (mgP/kg)		Direction of significant changes
	1998	2007	1998 - 2007
Upland Woodland			
Lowland Woodland	24.8	27.2	
Fertile Grassland	40.3	32.0	↓
Infertile Grassland	27.3	17.1	↓
Moorland Grass Mosaic			
Heath and Bog			
Tall Grass and Herb	42.3	33.0	
Crops and Weeds	45.4	41.3	

c) England – AVC unchanged

Aggregate Vegetation Class	Mean Olsen-P (mgP/kg)		Direction of significant changes
	1998	2007	1998 - 2007
Upland Woodland			
Lowland Woodland			
Fertile Grassland	40.1	32.3	
Infertile Grassland	26.2	15.6	↓
Moorland Grass Mosaic			
Heath and Bog			
Tall Grass and Herb			
Crops and Weeds	47.2	42.7	↓

d) England – Loss on Ignition Category

LOI Category (%)	Mean Olsen-P (mgP/kg)		Direction of significant changes
	1998	2007	1998 - 2007
Mineral (0-8)	39.4	34.2	↓
Humus-mineral (8-30)	34.6	24.4	↓
Organo-mineral (30-60)	36.0	23.9	↓
Organic (60-100)			

There were insufficient samples in 2007 in the Acid Grassland Broad Habitat to make a valid estimate of the mean. No significant change was observed in mean Olsen-P beneath Broadleaved, Mixed and Yew Woodland Broad Habitat in England between 1998 and 2007.

There were significant decreases in mean Olsen-P in the Fertile Grassland and Infertile Grassland AVCs in England between 1998 and 2007 ***(Table 6.4b)***. Of the AVCs with sufficient data to provide a valid estimate of the mean, the highest mean concentrations in 1998 and 2007 were observed in Crops and Weeds. Restricting the analysis to plots where AVC remained unchanged, resulted in only three AVCs having sufficient samples for statistically valid estimates of the mean ***(Table 6.4c)***. Mean values for Infertile Grassland, Fertile Grassland and Crops and Weeds for the unchanged dataset were very similar to those for the dataset as a whole. There were significant decreases in mean Olsen-P in Infertile Grassland and Crops and Weeds between 1998 and 2007 in the unchanged dataset.

Mean Olsen-P decreased significantly in all three LOI categories in England between 1998 and 2007 ***(Table 6.4d)***. The smallest change (13%) was observed in mineral soils and the largest in organo-mineral soils (39%). As a result in 2007, humus-mineral and organo-mineral soils had virtually the same mean Olsen-P concentrations (≈ 24 mgP/kg) which were approximately 10 mgP/kg less than for mineral soils. This represented an increase in the relative difference in mean Olsen-P between mineral soils and the other categories compared to 1998.

6.3.3. Change in mean Olsen-P concentration in soils (0-15cm) across Scotland

In 1998 and 2007, Arable and Horticulture (69 mgP/kg and 52 mgP/kg) and Improved Grassland (59 mgP/kg and 56 mgP/kg) Broad Habitats in Scotland had the highest mean Olsen-P concentrations amongst the three countries. There was a 25% decrease in mean Olsen-P in Scottish Arable soils (0-15 cm) between 1998 and 2007 but no significant change was observed for Improved Grassland ***(Table 6.5a)***. There was a significant decrease in mean Olsen-P in semi-natural grassland Broad Habitats in Scotland. Scottish Broadleaf Woodland soils (0-15 cm) had a much higher mean Olsen-P value (51 mgP/kg) in 1998 compared to England (34 mgP/kg) but too few samples were taken to provide a reliable estimate of the mean for Scotland in 2007.

Upland Woodland, Infertile Grassland, Moorland Grass Mosaic and Heath and Bog AVCs in Scotland all showed a significant decrease in mean Olsen-P concentration between 1998 and 2007 ***(Table 6.5b)***. There were no significant changes in Fertile Grassland or Crops and Weeds. The latter contained the largest mean concentration of Olsen-P in 2007 (50 mgP/kg) and AVCs in Scotland were more enriched in Olsen-P compared to the equivalents in England and Wales. Restricting the analysis to unchanged AVCs removed the Upland Woodland AVC, but for other AVCs, results were consistent with those for the dataset as a whole ***(Table 6.5c)***.

Table 6.5: Change in mean Olsen-P concentration of soils (0-15 cm) across Scotland for a) Broad Habitats, b) Aggregate Vegetation Classes (AVC) c) AVCs unchanged since 1978 and d) LOI categories. Arrows denote a significant change (p<0.05) in the direction shown. Diagonal line indicates too few samples to provide reliable value.

a) Scotland - Broad Habitat

Broad Habitats	Mean Olsen-P (mgP/kg)		Direction of significant changes
	1998	2007	1998 - 2007
Broadleaved, Mixed and Yew Woodland	50.9	╱	╱
Coniferous Woodland	39.9	29.5	↓
Arable and Horticulture	68.9	51.6	↓
Improved Grassland	59.1	56.2	
Neutral Grassland	28.4	24.9	↓
Acid Grassland	48.6	21.5	↓
Bracken	╱	╱	╱
Dwarf Shrub Heath	64.6	24.9	↓
Fen, Marsh, Swamp	╱	╱	╱
Bog	54.4	36.5	↓
All Habitat Types	49.1	32.8	↓

b) Scotland – AVC whole dataset

Aggregate Vegetation Class	Mean Olsen-P (mgP/kg)		Direction of significant changes
	1998	2007	1998 - 2007
All Woodland	╱	╱	╱
Upland Woodland	29.0	21.9	↓
Lowland Woodland	╱	╱	╱
Fertile Grassland	48.5	40.4	
Infertile Grassland	36.2	31.8	↓
Moorland Grass Mosaic	53.3	22.8	↓
Heath and Bog	54.8	33.9	↓
Tall Grass and Herb	╱	╱	╱
Crops and Weeds	60.9	49.5	

c) Scotland – AVC unchanged			
Aggregate Vegetation Class	Mean Olsen-P (mgP/kg)		Direction of significant changes
	1998	2007	1998 - 2007
All Woodland			
Upland Woodland			
Lowland Woodland			
Fertile Grassland	48.2	42.2	
Infertile Grassland	30.2	24.0	↓
Moorland Grass Mosaic	65.6	28.9	↓
Heath and Bog	46.3	29.5	↓
Tall Grass and Herb			
Crops and Weeds			

d) Scotland – Loss on Ignition Category			
LOI Category (%)	Mean Olsen-P (mgP/kg)		Direction of significant changes
	1998	2007	1998 - 2007
Mineral (0-8)	47.7	38.3	↓
Humus-mineral (8-30)	31.5	26.2	
Organo-mineral (30-60)	44.2	18.1	↓
Organic (60-100)	61.6	40.6	↓

The mean Olsen-P concentration in Scottish mineral soils decreased significantly between 1998 and 2007, but there was no significant change observed for humus-mineral soils ***(Table 6.5d)***. Organic soils in Scotland had a very high mean Olsen-P concentration in 1998 (62 mgP/kg) which decreased significantly in 2007 to 41 mgP/kg. Mean Olsen-P concentrations in organo-mineral soils decreased significantly by more than 60% between 1998 and 2007.

6.3.4. Change in mean Olsen-P concentration in soils (0-15cm) across Wales

The small number of samples from Wales placed a major restriction on data analysis, with only four reporting categories having sufficient data to provide valid statistics for status and change in Olsen-P ***(Table 6.6)***. The largest percentage change (41%) in the All Broad Habitats category was observed in Wales between 1998 and 2007 reflecting the large significant decrease (47%) in mean Olsen-P in the Improved Grassland Broad Habitat. Much of the Improved Grassland in Wales is located on humus-mineral soils which largely accounts for the significant decrease in Olsen-P between 1998 and 2007. Infertile Grassland was the only AVC in Wales to have sufficient sample points to provide valid statistics for stock and change ***(Tables 6.6b and 6.6c)***. Mean concentrations of Olsen-P in this AVC decreased significantly between 1998 and 2007 with or without changed AVC.

Table 6.6: Change in mean Olsen-P concentration of soils (0-15 cm) across Wales for a) Broad Habitats, b) Aggregate Vegetation Classes (AVC) c) AVCs unchanged since 1978 and d) LOI categories. Arrows denote a significant change ($p<0.05$) in the direction shown. Diagonal line indicates too few samples to provide reliable value.

a) Wales - Broad Habitat

Broad Habitats	Mean Olsen-P (mgP/kg)		Direction of significant changes
	1998	2007	1998 - 2007
Broadleaved, Mixed and Yew Woodland			
Coniferous Woodland			
Arable and Horticulture			
Improved Grassland	40.8	21.5	↓
Neutral Grassland			
Acid Grassland			
Bracken			
Dwarf Shrub Heath			
Fen, Marsh, Swamp			
Bog			
All Habitat Types	32.3	18.9	↓

b) Wales – AVC whole dataset

Aggregate Vegetation Class	Mean Olsen-P (mgP/kg)		Direction of significant changes
	1998	2007	1998 - 2007
Upland Woodland			
Lowland Woodland			
Fertile Grassland			
Infertile Grassland	21.4	14.3	↓
Moorland Grass Mosaic			
Heath and Bog			
Tall Grass and Herb			
Crops and Weeds			

c) Wales – AVC unchanged

Aggregate Vegetation Class	Mean Olsen-P (mgP/kg)		Direction of significant changes
	1998	2007	1998 - 2007
Upland Woodland			
Lowland Woodland			
Fertile Grassland			
Infertile Grassland	18.3	11.6	↓
Moorland Grass Mosaic			
Heath and Bog			
Tall Grass and Herb			
Crops and Weeds			

d) Wales – Loss on Ignition Category			
LOI Category (%)	Mean Olsen-P (mgP/kg)		Direction of significant changes
	1998	2007	1998 - 2007
Mineral (0-8)			
Humus-mineral (8-30)	30.9	17.4	↓
Organo-mineral (30-60)			
Organic (60-100)			

6.4 Discussion and Policy Implications

The results from Countryside Survey in 2007 show a significant decrease between 1998 and 2007 in mean Olsen-P concentrations in soils (0-15 cm) for most Broad Habitats, AVCs and LOI categories across Great Britain. Mean Olsen-P has remained unchanged in a few Broad Habitats and AVCs but no increases in mean Olsen-P have been observed. Changes in mean Olsen-P concentrations in Broad Habitats within individual countries between 1998 and 2007 reflect this pattern.

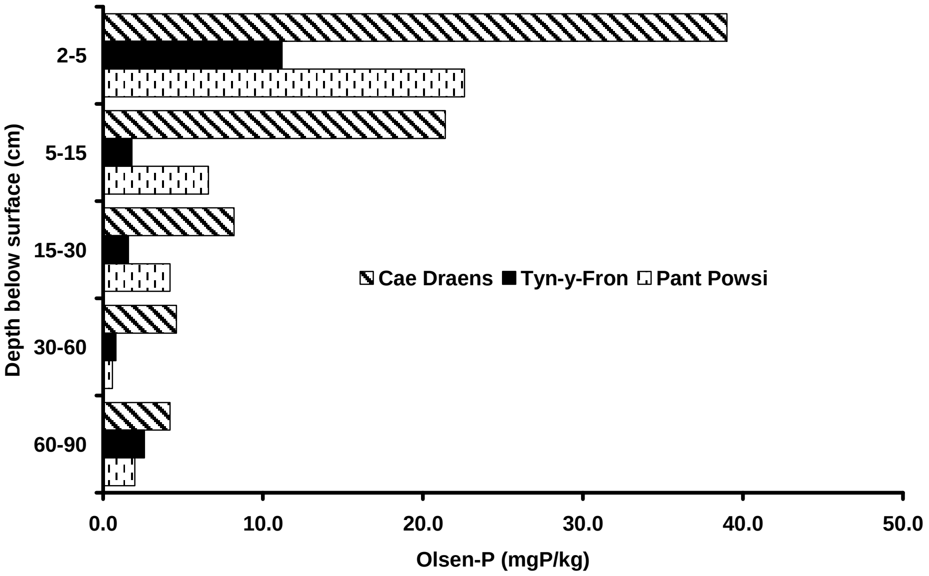
These results raise the question as to whether the changes observed between 1998 and 2007 are real or an artefact of field sampling and chemical analysis and whether the Countryside Survey data are consistent with those from other monitoring schemes. It is difficult to compare with results from other surveys due to the common use of mg/l for monitoring agricultural soils compared to mg/kg in CS.

The same sampling protocol was used in 1998 and 2007 but two important potential sources of sampling variability can be identified. The first of these arises because of the strong vertical gradient in Olsen-P concentration encountered in many soils under different vegetation types (see for example, ***Table 6.7*** and ***Fig. 6.6***). The highest Olsen-P concentrations are generally encountered in the surface soil layers (0-5 cm) which must be sampled consistently in repeat surveys if change is to be assessed accurately. A consistent failure to identify and sample the true soil surface layer could significantly bias results between surveys.

Table 6.7: Vertical distribution of Olsen-P (mgP/kg) in a) brown earth soil beneath neutral grassland at the Snowdon ECN site and b) stagnogley soil beneath improved grassland at Pontbren.

Snowdon ECN site			Pontbren (CEH unpublished data)		
	Olsen-P mgP/kg			Olsen-P mgP/kg	
Depth cm	Mean	Std Dev	Depth cm	Mean	Std Dev
0-5	27.4	22.3	2-5	23.4	4.0
5-10	16.3	11.2	5-15	10.4	2.5
10-20	7.8	2.5	15-30	5.6	2.6
20-30	5.3	1.0	30-60	3.3	1.6

Figure 6.6: Vertical distribution of Olsen-P (mgP/kg) in three blocks of farm woodland on stagnogley soils at Pontbren (CEH unpublished data).



A second source of error which affects all analytes arises because re-sampling in each Main Plot does not occur at exactly the same spot. The cores in 1998 and 2007 were taken from points located 2-3 m apart from permanently marked locations (Chapter 1). This will introduce random variability into the data due to small scale heterogeneity in soil properties alongside any surveyor error in re-locating the plots. The size of the effect is unknown but is unlikely to have caused systematic bias between the surveys and there is significantly less potential for relocation error in CS relative to NSI where no permanent markers are used.

The quality of the chemical analyses for 1998 and 2007 has been discussed in ***Section 6.2.1***. Taken overall the Quality Control data show strong consistency within and between the measurements made in 2002 and 2008 and give little cause for concern regarding a comparison of Olsen-P data from 1998 and 2007.

Countryside Survey Olsen-P data are broadly consistent with results from other surveys and monitoring sites ***(Tables 6.8 and 6.9)***. Fixed depth sampling at the ECN sites does not include 0-15 cm depth but the data broadly confirm values measured by Countryside Survey. The ECN data further illustrate the strong vertical gradient in Olsen-P concentrations across a range of land use and habitat types.

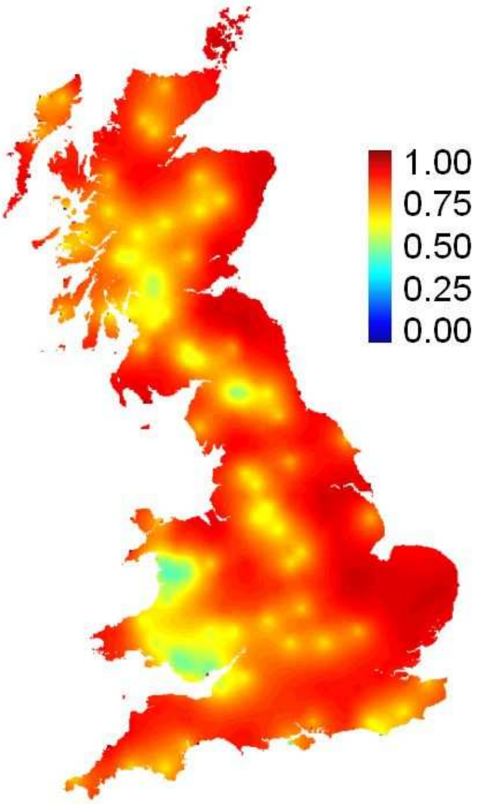
Table 6.8: Olsen-P concentrations measured in Arable and Improved Grassland in the National Soil Inventory in 1980 and 1996 from Bradley *et al.* (2003).

Broad Habitat	Olsen-P mgP/kg NSI 1980 (0-15 cm)	Olsen-P mgP/kg NSI 1996 (0-15 cm)
Arable	33.0	42.8
Improved Grassland	22.7	22.9

Table 6.10: Olsen-P concentrations measured at two depths in soils at selected Environmental Change Network sites. Samples were not collected at 0-15 cm depth at the ECN sites.

ECN site name	Land use	Olsen-P mgP/kg 0-5 cm depth	Olsen-P mgP/kg 5-10 cm depth
Drayton	Permanent pasture	93.7	41.6
North Wyke	Permanent pasture	67.3	35.7
Snowdon	Upland grassland	27.4	16.3
Wytham	Deciduous woodland	22.7	11.4
Alice Holt	Oak woodland	13.5	6.5

Figure 6.7: Map of probability of 2007 Olsen-P concentration being greater than 18 mgP/kg. Probability scale between zero and one.



Analysis of the 2007 Olsen-P data revealed very little spatial structure which is reflected in the map which predicts the probability on exceeding the threshold of 18mgP/kg on a scale from zero to one, a value of one indicating the threshold has been exceeded ***(Fig. 6.7)***. Visual inspection of the mapped data for Olsen-P from the NSI (McGrath and Loveland 1992) showed a broad separation in Olsen-P concentrations between areas of managed agricultural land in central, southern and eastern England and those under semi-natural vegetation and forest mainly in the north and west. Within the areas of managed land there was a wide range of concentrations with large differences in values between adjacent NSI mapping units. Probability maps for Olsen-P from the RSSS (Baxter *et al.*, 2006) show some limited correspondence between the map for the 2001 RSSS data and Countryside Survey. It is important to remember the differences in sampling strategy and survey design when comparing the data from these three surveys, but it is generally apparent that there are no strong spatial patterns in Olsen-P concentrations.

Assuming that the Countryside Survey data from 1998 and 2007 provide valid estimates of Olsen-P across Great Britain, a number of hypotheses can be invoked to account for the decrease observed over the nine year period. These are briefly discussed below as detailed exploration is beyond the scope of this Report.

Reduction in external inputs of phosphorus- Data on fertiliser use compiled as a core indicator under the Defra Sustainable Farming and Food Strategy showed a 53% decline in the total use of phosphate fertiliser between 1984 and 2007 in England. Across Great Britain, application rates of phosphate (P_2O_5) to tillage crops decreased from 51 kg/ha to 32 kg/ha and to grass from 21 kg/ha to 14 kg/ha between 1998 and 2007 (BSFP 2008). The figures for 2007 correspond to the lowest application rates since statistics were first compiled in 1983 and presumably reflect changes in agricultural management in response to environmental and economic pressures (Baxter *et al.,* 2006).

Taking England as an example, combining application rates with agricultural land area data from the June Agricultural Survey, showed a large decline in phosphate use. Total application of phosphate in England in 2007 was 123 kT P_2O_5 to tilled land and 48 kT to grassland compared with 209 kT and 72 kT respectively for 1998. Soil phosphorus status in enclosed agricultural land will also be influenced by more subtle changes in crop and livestock management and by changes in the type of fertiliser used. Oliver *et al.* (2006) commenting on the decrease in Olsen-P observed in the RSSS between 1971 and 2001, attributed the decline to a steady reduction in phosphorus fertiliser inputs but also noted that for grassland there had been a progressive shift away from insoluble forms of phosphorus fertiliser such as rock phosphate to more water soluble materials. Deeper ploughing will also bring subsoil with a relatively low phosphorus status to the surface. This would dilute the existing topsoil phosphorus stock unless fertiliser was added.

The amount of phosphorus deposited annually across Great Britain from the atmosphere is poorly quantified with a recent estimate for the United Kingdom of 0.3 kgP/ha/yr (White 2006). Phosphorus concentrations in rain are low and the main vector is dry deposition of dust. As far as can be ascertained, there are no data to describe trends in atmospheric phosphorus inputs to Great Britain over time. Use of clean-up technology for sulphur emissions from coal burning may have led to a decline in phosphorus emissions with a knock on effect on atmospheric deposition. A reduction in mineral fertiliser use would also reduce the amount of particulate phosphorus in the atmosphere derived from re-suspended soil. The quantities of phosphorus deposited on semi-natural systems are likely to be relatively small but there is little information as to how they compare to inputs from sources such as mineral weathering.

Effect of atmospheric nitrogen deposition- A number of studies have reported that non-agricultural ecosystems in Great Britain could be moving towards phosphorus limitation in response to increased availability of nitrogen from atmospheric deposition. In moorland vegetation high foliar N:P ratios have been correlated positively with nitrogen deposition (Kirkham 2001). On the Carneddau in Wales montane heath vegetation had relatively high foliar N:P ratios compared with similar systems receiving less atmospheric nitrogen deposition in Scotland (Britton *et al.,* 2005). Both studies have been cited as examples of potential phosphorus limitation. In contrast, Rowe *et al.,* (2007) reported that foliar N:P ratios in *Calluna* collected during 1998 decreased with nitrogen deposition. They suggested that enzyme production or mycorrizal activity may have allowed *Calluna* to access additional soil phosphorus resources. In upland plantation Sitka spruce forests, root bioassay techniques have shown increased phosphorus demand in older crops where excess nitrogen was leached as nitrate in soil and stream waters (Harrison *et al.,* 1995). The authors inferred that supplies of available phosphorus in soils may have limited the ability of older trees to utilise incoming atmospheric nitrogen. Phosphorus deficiency has also been reported in Dutch forests receiving large amounts of nitrogen deposition probably because of soil acidification (Mohren *et al.,* 1986).

The overall implication of these studies is that sustained levels of atmospheric nitrogen deposition may have increased plant demand on soil phosphorus resources. In the soil, this may have decreased the size of the labile phosphorus pool (as measured by Olsen-P) at a time when external sources of phosphorus may also have declined.

***Effects of pH change on phosphorus binding capacity in soils* –** The chemistry of phosphorus in soils is complex and pH dependent through a number of processes related to the clay mineral content and presence of sesquioxides and exchangeable aluminium in the soil. In fertilised alkaline soils or calcareous soils phosphorus availability is greatest between pH 6 and pH 7. As pH in these soils increases above about pH 6.5, phosphate solubility decreases rapidly with the formation of insoluble calcium salts which contribute to the unavailable or non-labile soil phosphorus pool. In acid mineral soils, phosphate ions combine readily with iron and aluminium to form insoluble compounds whilst fixation by hydrous iron and aluminium oxides and clay minerals can sequester large amounts of phosphorus. As pH increases, so does the solubility of basic iron and aluminium phosphates (solubility minima between pH 3 and 4) and some of the fixed phosphorus will also be released, resulting in a maximum pool of readily available phosphorus at soil pH values between 6 and 6.5 (Brady 1974).

Soil pH increased significantly across many Broad Habitats, AVCs and soil LOI categories between 1998 and 2007. In the Broad Habitats and AVCs representative of managed agricultural land, mean soil pH across Great Britain was well above pH 6 and was over pH 7 in the Arable and Horticultural Broad Habitat and Crops and Weeds AVC in 2007. If calcium was abundant in these soils, the high pH values would favour the formation of insoluble salts and may reduce the pool of more labile phosphorus. In many of the Broad Habitats and AVCs which would typically have more acid mineral soils (e.g. Acid Grassland Broad Habitat, Moorland Grass Mosaic AVC), soil pH did not increase significantly between 1998 and 2007, and mean values were typically around pH 4.5. In this pH range, the relatively available pool of soil phosphorus would still be small compared with that fixed by hydrous oxides of iron and aluminium or held in precipitates. Sustained atmospheric nitrogen deposition may have increased plant demand on this pool particularly in systems where grazing or other forms of biomass harvesting result in nutrient removal from the site.

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7. Soil metal concentrations

Summary

- **A comparison of back corrected Countryside Survey soils (0-15cm) analyses for 1998 and 2007 samples indicated that, as would be expected, only relative small changes in soil trace metal concentrations occurred between surveys despite reported declines in atmospheric deposition due to the long residence time of metals in soils.**
- **Of seven metals for which repeat measurement were made during the 2007 survey, only for one, Cu, was a statistically significant difference in soil (0-15cm) concentrations (an increase) found at the GB level.**
- **When the data for repeat metal measurements were stratified by Broad Habitat, Aggregate Vegetation Class and soil organic matter category, further statistically significant differences were seen. For Cu generally significant increases were observed whilst for two metals, Cd and Pb, changes were small and idiosyncratic between stratifications. For three metals, Cr, Ni, Zn, changes were generally characterised by reduction in crop lands and no change or slight increases in less managed habitats.**
- **For some metals, such as Cu and Cd it is likely that additional sources (animal manures and possibly sewage sludge, manures and compost for Cu and fertiliser for Cd) beyond atmospheric inputs are important in maintaining or even increasing soil concentrations principally in managed areas. For the remaining metals, especially Cr, Ni and Zn, there is some suggestion that in areas where cropping takes place, output fluxes may now exceed inputs enabling soil concentrations to decline.**
- **Managed landscape where intensive cropping takes place, but sewage sludge, animal manures and composts are rarely applied, may be among the first habitats to return from their slight-moderately elevated states to their pre-industrial background concentrations and could be a focus for future monitoring.**

7.1 Policy background

Key Question: *Is the decline in atmospheric deposition as reported by the Heavy Metals Monitoring Network reflected in soil metal concentrations measured with CS?*

Measurements: Concentrations of Cd, Cr, Cu, Ni, Pb, V and Zn is soils (0-15cm) collected in repeat sampling of plots that were also sampled and analysed for the same metals in 1998; measurement of concentrations of Li, Be, Al, Ti, Mn, Fe, Co, As, Rb, Se, Sr, Mo, Sb, Sn, Cs, Ba, W, Hg, U in CS in 2007 soil samples as an initial survey of a wider range of trace element. From this analysis CS in 2007 has provided:

- **Whole Great Britain (GB) and Broad Habitats, Aggregate Vegetation Classes (AVC) and soil type stratified assessments of soil trace element concentrations in soil (0-15cm) in 2007.**
- **Information of the change in concentrations of trace metals (Cd Cr, Cu, Ni, Pb, V, Zn) in GB soil (0-15 cm) since previous measurements made at the same plots in 1998.**
- **Data to contribute to analysis of source changes in the distribution of trace elements in a range of GB habitats, vegetation types and soil classes.**

Background

In the European Union and internationally, a set of research programmes have focused on assessing the risks of trace metals to ecosystems. This work has been driven by policy initiatives which include new procedures for the mandatory risk assessment according to European Commission regulation 1488/94 and studies to support the 1998 Convention on Long-Range Transboundary Air Pollution Aarhus Protocol on Heavy Metals. The focus of policy makers and researchers on the risk assessment of metals recognises the harm that elevated trace element concentrations can do to soil ecosystems. A number of keystone soil taxa (e.g. earthworms, springtails, nitrifying bacteria) are particularly sensitive to metals. High metal concentration in soils can reduce the abundance and diversity of communities of these and other taxa, potentially resulting in a breakdown of specific soil functions such as decomposition, nutrient turnover and the regulation of hydrological flows through soil. Metals are not broken-down over time (unlike most organic chemicals), and so can be removed only by the relatively slow process of cropping and leaching, the accumulation of metals offers one of the more serious long-term threats to soil sustainability worldwide.

The environmental risks of metals for UK soils are currently being asssed in two projects; improving current critical loads methods for application within UN/ECE Convention and developing models that can be used to describe and predict the effects of changes in input rates on soil and freshwater metal pools. Both project will benefit from good quality soil metal survey data. Key measurements required include information on current concentrations of metals in soils (representing combined geogenic and past anthropogenic inputs); and also predicted rates of change. Modification in metal concentration in surface soils will represent the balances between input fluxes associated with natural and anthropogenic inputs and output fluxes associated with crop removal and leaching.

Measurements of the input rates of atmospheric metal deposition to rural soils in the UK since 2004 have come from analyses of rain water and airborne particulate metal concentrations made within the UK ‘Heavy Metal Deposition Monitoring Network’. This network has collected information on the concentrations of a suite of metals of regulatory interest including Cd, Cu, Ni, Pb, Zn and Hg. Other important routes for the input of metals to soils are associated with the addition of sewage sludge, animal manures and other solid waste streams to soils principally in agricultural areas. Information on these inputs can be derived from Defra supported long-term monitoring projects focussing on solid waste receiving systems. For estimates of losses from cropping and leaching, prediction of removal rates have been made by modelling studies conducted to support development of a critical loads approach for metals in soils. Despite this knowledge, because the Heavy Metal Deposition Network covers only a small number of sites (15 in GB) and there is little large scale data on the local patterns of solid waste inputs and cropping and leaching removals available, the input and output flux estimates that are currently available are very uncertain.

Although uncertain and spatially variable, estimates made by the Heavy Metal Deposition Monitoring Network, other large-scale monitoring programs and by source inventory assessment have suggested that rates of atmospheric metal deposition to UK soils are declining. For example, a European wide survey of trace metal concentration in over 6000 moss samples identified a decline in concentrations of As of 72%, Pb of 72%, V of 60%, Cd of 52% and Fe of 45% between 1990 and 2005. Smaller declines were also found for Zn of 29%, Cu of 20% and Ni of 20%. Declines for Hg (12%) and Cr (2%) were not significant. While it is apparent that atmospheric deposition is likely to be declining, it is not known whether these reductions have yet passed the point beyond which output losses exceed inputs and so overall metal concentrations can begin to decline. Dynamic modelling within Defra funded projects on critical loads assessment have suggested that the residence time of metals in soils will be at least many decades and for some metals, such as lead, possibly millennia (Tipping *et al.*, 2006a). Extensive datasets on the rates of change of concentrations of metals in soils are not currently available to validate these model predictions. By resampling and measuring soil metal concentration in samples collected countrywide after a 9 year gap, it was hoped that CS could provide an initial prototype of just such a dataset.

7.2 Methods

7.2.1 Proof of concept

As part of the Measuring and Assessing Soil Quality of CS in 1998, over 1100 soil samples were successfully analysed for seven trace metals (Cd, Cr, Cu, Ni, Pb, V, Zn) using aqua regia digestion and an ICP-OEC analysis method. Measured concentrations showed regional trends with higher value generally found in England and Wales than in Scotland. Concentrations also differed between Broad Habitats, with highest concentrations in Arable and Horticulture and Improved Grassland soils and lowest concentrations in Dwarf Shrub Heath and Bogs. The GB wide sampling and measurement programme of CS in 1998 provided information on the concentrations of metals in the rural soils that are the focus of CS rather than urban or industrial soils that are often considered in pollution assessment programs. These rural soils are primarily influenced by diffuse, rather than point source, inputs and so are relevant to studies to assess the potential for large scale pollution effects resulting from diffuse exposure.

To provide initial knowledge on the potential dynamics of metal concentrations in GB soils, a repeat analysis of a sub-set of samples collected within CS in 1998 has been undertaken as part of CS in 2007. This was done to allow the key policy question of interest to stakeholders to be addressed, namely *Is the decline in atmospheric deposition as reported by the Heavy Metals Monitoring Network reflected in soil metal concentrations measured with CS?* To address the highlighted policy issue and assess wider implications relating to metal distribution of GB soils, the metal component of CS in 2007 was designed to provide:

- **A nationwide assessment of the concentrations of 26 metal or metalloid elements, namely lithium (Li), beryllium (Be), aluminium (Al), titanium (Ti), vanadium (V), chromium (Cr), manganese (Mn), iron (Fe), cobalt (Co), nickel (Ni), copper (Cu), zinc (Zn), arsenic (As), rubidium (Rb), selenium (Se), strontium (Sr), molybdenum (Mo), cadmium (Cd), antimony (Sb), tin (Sn), caesium (Cs), barium (Ba), tungsten (W), mercury (Hg), lead (Pb), uranium (U) in almost 500 GB soils collected in CS in 2007.**
- **Information on the change in concentrations of metals in GB soils for seven metals (Cd, Cr, Cu, Ni, Pb, V, Zn) that were also analysed in CS samples collected in 1998 and in the 2007 repeat analyses.**
- **An assessment of the influence of Broad Habitats, AVC and soil type on measured metal concentration and rates of change between survey years.**

Countryside Survey in 2007 has provided a large-scale re-sampling of soil metal concentrations with the framework of an integrated nationwide monitoring program. The full rationale for the repeat measurement of soil metal concentrations is set out in ***Table 7.1*** and the progression of the development of the resampling and analysis approach used set out in detail below.

In CS in 1998, concentrations of Cd, Cu, Cr, Ni, Pb, Zn were measured in soils collected from all Main Plots within squares first sampled for soil (pH, LOI, soil texture) in the 1978 survey ***(Chapter 1).*** This gave a potential total of 1256 soils for metals analysis, although actual numbers were somewhat lower due to plot or sample losses meaning that in total 1119 soils were actually analysed. Competing priorities for resources during the design of the 2007 survey and measurement program meant that, within the available budget, a full analysis of all previous analysed Main Plots re-sampled in CS in 1998 could not be supported. During preparation for CS, a power analysis of the 1998 survey data was conducted to evaluate within and between square variability and to assess the implications of changing sample number for the power of the analysis to detect change in metal concentrations. Results of this power analysis indicated lower within square than between square variability. Further it was indicated that a reduction in the number of Main Plots analysed per square, from 5 in CS in 1998 to only 2 in CS in 2007, would actually have only a very limited effect on the power to detect change in CS in any repeat analysis. Based on this evaluation, in 2007 metals analysis was limited to two Main Plots for all squares previously samples in 1978..

Table 7.1: Summary of rationale for measurement of soil metal concentrations within CS in 2007.

Issue	Facts	Comments
History in CS	Measured in 1097 samples in CS in 1998.	Measurement of 2007 re-samples will give capability to establish a time series for the first time.
Country level reporting	No	CS in 1998 did not give country level statistics. Reduced dataset in 2007 limits the power of analysis for Country level reporting for habitat, vegetation and soil types stratifications.
Links and compatibility to other monitoring programmes	UK heavy metal monitoring network. BGS G-BASE for soils and stream sediments. Comparable data to those collected in the NSI, for same horizon (0-15cm). Environment Agency Soil and Herbage Survey.	Potential to link soils metal levels with predicted deposition. Able to link soil metal levels with stream sediment database. Can compare CS to NSI metal concentrations. Can compare with data for rural, but not urban or industrial site soils.
Uniqueness of CS	The only national dataset that reports on metal distribution and trends within an integrated monitoring programme.	Increase scope by inclusion of additional trace element analytes within an extended analytical suite.
Value for money (Policy priority or interpretative value x cost)	Priority - medium Value for money - medium	Sound fit with current priorities and good fit with existing projects. ICP-MS and ICP-OES method delivers data on 26 metals and also on total P and total S.

In the intervening period between the analysis of the CS in 1998 samples and the collection of samples from CS in 2007, several analytical developments were introduced into the procedures for trace metal analysis used at the UKAS accredited analytical facility at CEH in Lancaster. During the movement of the metal analysis laboratory from its previous location at CEH Merlewood, it was necessary to dismantle the hotplate reflux system that was used for digestion of all soils in CS in 1998. Logistical requirement meant that the equipment could not be rehoused in the new analytical laboratories at CEH in Lancaster. Instead it was decided to procure a new microwave digestion system that would be used for soil digestions. Although both systems use aqua regia as the reagent for digestion, the change in available instrumentation for conducting digestion from a hot plate reflux system to microwave digestion still could have the potential to confound the comparison of the 1998 and 2007 data, if the two method show different extraction efficiencies. Before detailed analysis of the data was conducted, a careful comparison of the two methods was conducted using the available quality assurance information to check the comparability of the two methods.

In addition to a change in digestion apparatus, purchase of new equipment for the analysis laboratory meant that as well as Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES), a further detection method, Inductively Coupled Plasma Mass Spectrometry (ICP-MS) could also be used in CS in 2007. In the preparatory work for CS in 2007 the accuracy and precision of the two detection methods was compared for a representative set of aqua regia digests of 1998 CS soils. Results indicated a good comparability between the two detection techniques. Since the resource implications for the use of the two instruments in parallel were minimal, it was decided to use a comprehensive approach for the full analysis that included use of both procedures. This approach both ensured any new analytical measures were compatible with CS in 1998 measures from digests and also delivered concentrations for an extended analyte suite. The analytical strategy used involved a 5 stage approach based on 1) aqua regia digestion; 2) analysis by ICP- OES for Cd, Cr, Cu, Pb, Ni, V, Zn, P and S; 3) further analysis of the same samples for further metals by ICP-MS; 4) careful data evaluation, 5) targeted re-measurement for any problem analytes.

7.2.2 Analytical method

The field method used for soil core collection at each Main Plot was the same as in CS in 1998. The cores used for metal analysis were collected using a 15 cm long by 5 cm diameter black plastic core following the detailed field protocol set out in Emmett *et al.* (2008). Once extracted and logged, all cores were returned by mail to CEH in Lancaster, as the quickest route of return. On receipt, samples for metal analysis were taken from the 'Black core' (See Emmett *et al.*, 2008, Annex 1).

A total of 1054 black cores were collected from the 5 Main Plots in the original 256 1978 squares. From this total number, a subset of two cores from each visited square was chosen for trace metal analysis. Cores were chosen at random from the subset of collected samples that were also analysed for concentrations of mineralisable nitrogen (see Chapter 5). All metal analyses were carried out by the UKAS accredited inorganic analysis laboratory at CEH in Lancaster. After initial processing of the core to obtain a homogenous sample (See Emmett *et al.*, 2008, Annex 1), soil samples were ball-milled before analysis. A 0.5g sub-sample of the dried milled material was used for analysis. Digestion of the soil samples was conducted using an aqua regia mixture (3 ml of 37% hydrochloric acid and 9 ml of 69% nitric acid both 'aristar' grade reagents) employing microwave heating under pressure. The microwave digestion method was adapted from that used by the US EPA (method # 3051A) to fit the specific requirements of the available digestion equipment at CEH in Lancaster. The use of microwave digestion differed from the procedure used for measurement of soil metal concentration in CS in 1998 as outlined previously. As a result of the change in digestion procedure, detailed checks of the quality assurance data were conducted to verify the comparability of the analysis methods (see quality assurance section below). Further, a series of validation checks have also been conducted of samples measured in the CS in 1998 using the CS in 2007 protocol. This targeted re-measurement includes samples of a range of soil LOI and pH values and has been used in combination with available quality control information to support interpretations within this report.

After digestion, all samples were prepared for analysis of Cd, Cr, Cu, Ni, Pb, V, Zn, P and S using ICP-OES and the technical method and operational limits relevant to the selected analytes. Additionally for each digestion, a parallel analysis was conducted that measured concentration of a suite of additional elements namely Li, Be, Al, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Rb, Se, Sr, Mo, Cd, Sb, Sn, Cs, Ba, W, Hg, Pb, U using ICP-MS. For reporting, all values for metal concentrations derived from both detection methods were expressed as mg/kg (equivalent to ppm and μg/g) on a dry weight basis.

Table 7.2: Summary of quality control data for measurement of certified reference soil BCR, CRM141R. The table highlights the repeatability of the measurements made in 1998 (top) and 2007 (middle), but also the difference in the measured quantity resulting from the necessitated change in digestion procedure between CS in 1998 and CS in 2007. The bottom table shows a comparison of the mean measured total of Cd, Cr, Cu, Ni, Pb, V and Zn made using the different method in each survey and the estimation of the correction factor used to back correct CS in 1998 samples to account for digestion related differences. Subsequent data analyses was done comparing back corrected CS in 1998 measurements with uncorrected CS in 2007 measured concentrations.

1998 CS2000 Reflux digestion/ICPOES measurement. BCR, CRM141R

Mg/kg	Cd Mg/kg	Cr Mg/kg	Cu Mg/kg	Ni Mg/kg	Pb Mg/kg	V Mg/kg	Zn Mg/kg
mean	13.60	141.00	47.00	97.30	48.60	50.30	261.00
sigma	0.70	5.30	1.70	3.70	3.30	2.10	9.30
CV	5.15	3.76	3.62	3.80	6.79	4.17	3.56
certified	14.00	138.00	46.90	94.00	51.30	n/a	270.00
% recovery	97.14	102.17	100.21	103.51	94.74	n/a	96.67
bias	-0.40	3.00	0.10	3.30	-2.70	n/a	-9.00
% bias	-2.86	2.17	0.21	3.51	-5.26	n/a	-3.33
error	1.80	13.60	3.50	10.70	9.30	n/a	27.60
Error %	13.24	9.65	7.45	11.00	19.14	n/a	10.57

2008 CS2007 microwave digestion/ICPOES (-oes) or ICPMS (-ms) measurement. BCR, CRM141R

	Cd-ms Mg/kg	Cr-ms Mg/kg	Cu-oes Mg/kg	Ni-ms Mg/kg	Pb-ms Mg/kg	V-oes Mg/kg	Zn-oes Mg/kg
Mean	12.70	121.20	46.70	83.66	49.54	35.80	284.60
sigma	0.16	1.30	0.60	1.13	0.81	1.90	5.40
CV	1.26	1.07	1.28	1.35	1.64	5.31	1.90
Certified	14.00	138.00	46.90	94.00	51.30	n/a	270.00
%recovery	90.71	87.83	99.57	89.00	96.57	n/a	105.41
bias	-1.30	-16.80	-0.20	-10.34	-1.76	n/a	14.60
%bias	-9.29	-12.17	-0.43	-11.00	-3.43	n/a	5.41
Error	1.62	19.40	1.40	12.60	3.38	n/a	25.40
Error%	**12.76**	**16.01**	**3.00**	**15.06**	**6.82**	**n/a**	**8.92**

BCR, CRM141R – 1998:2007 comparison all validation

	Cd-ms Mg/kg	Cr-ms Mg/kg	Cu-oes Mg/kg	Ni-ms Mg/kg	Pb-ms Mg/kg	V-oes Mg/kg	Zn-oes Mg/kg
1998	13.60	141.00	47.00	97.30	48.60	50.30	261.00
2007	11.82	109.89	43.27	78.72	47.24	28.20	266.32
1998:2007	1.15	1.28	1.09	1.24	1.03	1.78	0.98

7.2.3 Quality assurance

Within each batch of 20 samples, a minimum of one blank, and two certified reference material (CRM), and one local reference material (LRM) were always analysed. The two CRMs used were the BCR CRM141R calcareous loam soil and International Soil Exchange ISE 921 river clay both of which have certified values for a range of metals included within the analytical suite. Quality control checks for each analytical batch were conducted to ensure that total analytical error was not greater than 20% comprising a 10% error in precision, and 10% error in bias. This criterion is more rigorous than that used by the Environment Agencies MCERTS performance standard for laboratories undertaking chemical testing of soil (N.B. MCERTS defines total allowable error of 25% - 10% bias + 15% precision).

For the 2007 soils analysed using microwave digestion with ICP-OES or ICP-MS detection, certified values for the repeat analysed metals (Cd, Cr, Cu, Ni, Pb, Zn) indicated that the total error of the method is within the allowable 20%. Compared with results from the CS in 1998 survey, the analytical method used in CS in 2007 provided a similar and in both cases satisfactory precision of measurement in all cases (***Table 7.2***). This confirms the suitability of the method used. Even though both the microwave and hotplate digestion method performed within quality assurance targets, it must be remembered that both digestion procedure remain operationally defined. This means that the two aqua regia digestion based techniques do not give a full measurement of all metals present in soils. Some metal remains unextracted. These residual ions are, however, mostly bound to silicate minerals and as such are widely considered to be unimportant for estimating the mobility and behaviour of trace elements in soil. This operational component to the effectiveness of the method does, however, raise the potential for the two procedures to produce slightly different estimates of metal concentrations from the same soil.

To provide a cross check between measurements made by the two different digestion methods, two separate approaches were used. For the first, a comparison was made of the measurements made of the BCR CRM141R calcareous loam soil which was extensively analysed during both the CS in 1998 and CS in 2007 measurement campaigns. Comparison of quantifications of the CRM in the two surveys indicated that 6 of the 7 metals showed higher concentrations in BCR CRM141R soil in CS in 1998 than in CS in 2007 (***Table 7.2***). Cd, Cr, Cu, Ni and Pb showed concentrations that were between 3% (Pb) and 28% (Cr) higher in CS in 1998. Concentrations of V in CS in 1998 were 78% higher in the CRM in measurements made in CS in 1998 than in CS in 2007. Of measured metals in the CRM, only Zn concentrations were lower (by 2%) in CS in 1998 than in CS in 2007.

The second approach to comparison of the two digestion techniques was through a repeat analysis of samples that were originally measured following hotplate reflux digestion as part of the CS survey in 1998, but this time using the CS in 2007 microwave method. Twenty six samples that had been archived from the 1998 survey were digested using the microwave method and analysed for concentration of the seven trace elements (Cd, Cr, Cu, Ni, Pb, V, Zn) that were originally measured during the 1998 analysis. The results of this targeted re-measurement confirm the initial indication gained from the comparison of certified reference material analyses in all cases except for V. The method comparison highlights that there is an approximate 30% increase in measured Cr and Ni concentrations using the reflux technique; Cd and to a lesser extent Cu concentrations are also marginally higher with hotplate reflux (3-10%); while Pb and Zn concentrations are similar to within a few percent using both methods (***Table 7.3***). For V the comparison between soils highlights a small underestimation of concentrations using reflux, while in contrast a large overestimation was indicated by the CRM comparison.

Table 7.3: Summary data for measurement of soil trace metal concentrations measured in selected (26) soil samples collected in CS in 1998 using the hot reflux digestion protocol used for all CS in 1998 analyses and also the microwave digestion protocol used for analysis in CS in 2007 samples. The table highlights the repeatability of the measurements made in 1998 (top) and 2007 (middle), but also the difference in the mean measured total of Cd, Cr, Cu, Ni, Pb, V and Zn made using the different methods as shown by the comparison of measured concentration between the two procedures.

	Cd-ms mg/kg	Cr-ms mg/kg	Cu-oes mg/kg	Ni-ms mg/kg	Pb-ms mg/kg	V-oes mg/kg	Zn-oes mg/kg
1998 soils by reflux	0.36	35.75	17.03	28.47	67.38	41.45	0.00
SD	0.26	52.19	17.54	54.87	98.35	38.59	42.22
1998 soil by microwave	0.34	0.55	0.44	0.52	0.41	0.45	0.41
SD	0.23	39.37	15.15	42.82	93.92	38.38	41.96
Reflux/Microwave	1.11	1.31	1.03	1.36	0.96	0.98	0.97
SD	0.40	0.64	0.17	0.57	0.13	0.16	0.13

Because the differences relating to the efficiency of the digestion techniques used between surveys could contribute to any indicated differences between surveys, it was decided to “normalise” one set of measurements to allow direct comparison. As the 2007 measurements showed the highest precision for the majority of the metals measured in both surveys (Cd, Cu, Pb, Zn) and the microwave digestion method will be applied in future soil metal research within CEH, including any potential future CS analyses, it was decided to normalise the 1998 data to give concentration estimates for soil collected in 1998 assuming analysis conducted according to the CS in 2007 method. The back correction of the 1998 concentrations was achieved by dividing the measured value by the ratio of mean 1998 : 2007 measurements for the BCR CRM141R reference soil. Correction was undertaken according to measurement in the reference soil for two reasons. Firstly, these analyses were made at the same time that the CS soils themselves were measured, meaning that they are most likely to relate to operational conditions at the time of CS sample assessment. Secondly, the CRM dataset contains a greater number of total measurements than the repeated 1998 dataset. The back correction of the 1998 measurements gives an estimated value for 1998 soils if measured using the 2007 protocol. The back correction procedure, was conducted for 6 metals Cd, Cr, Cu, N, Pb, Zn, but not for V. This was because the large discrepancy in BCR CRM141R measurement between surveys for this metal (78%) and the mismatch between this comparison and the repeat measures, questions the reliability of the extraction method and data “normalisation” approaches used for this metal. As a result, V has been excluded from the analysis of change between surveys.

Figure 7.1: Comparison of change in measure metal concentration following back correction of 1998 data to account for differences resulting from changes in digestion procedure between the 1998 and 2007 survey in relation to pH of the measure soil. Red line indicates linear trend of change in relation to pH. Absence of a strong trend for change in relation to soil pH indicate that there is no effect of soil pH on the size of the difference resulting from the digestion change meaning that a single value for back correction is applicable to soils independent of pH.

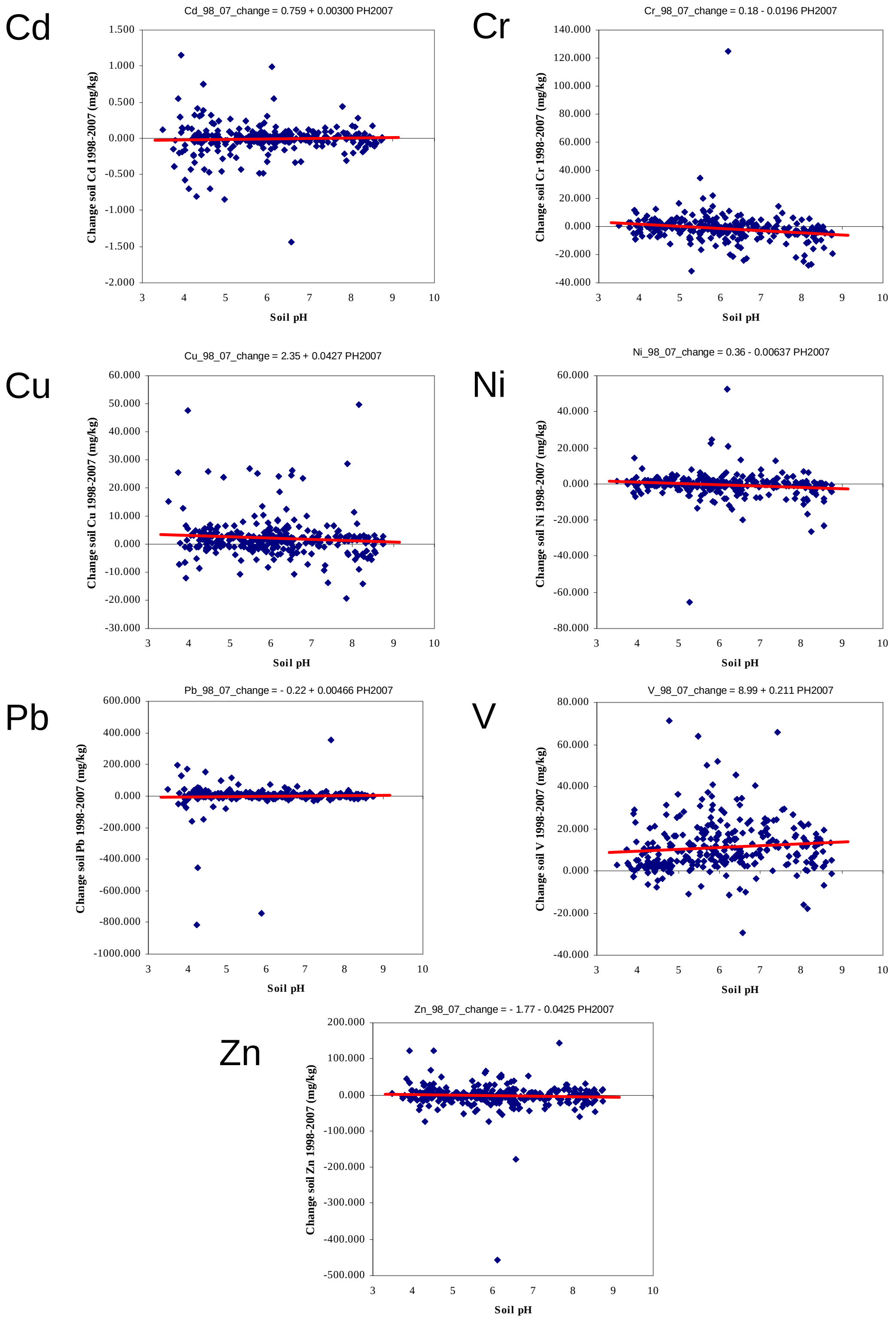
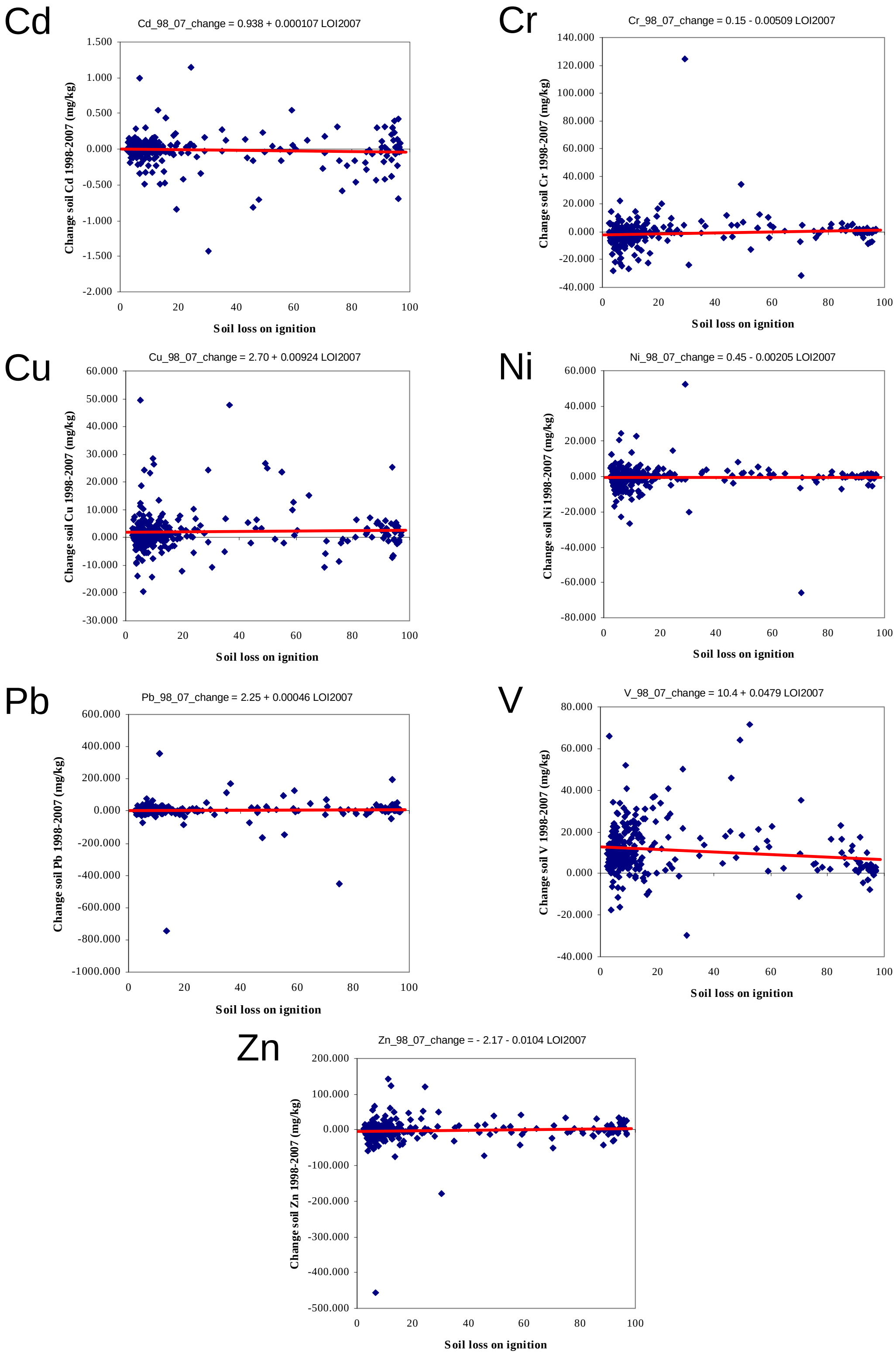


Figure 7.2: Comparison of change in measure metal concentration following back correction of 1998 data to account for differences resulting from changes in digestion procedure between the 1998 and 2007 survey in relation to soil LOI. Red lines indicate the linear trend for change as a function of LOI. Absence of a strong trend for change in relation to soil pH indicate that there is no effect of soil pH on the size of the difference resulting from the digestion change meaning that a single value for back correction is applicable to soils independent of LOI.



A potential concern with the back correction approach used to “normalise” measurements between surveys was that this could results in the false identification of change in some habitats if the difference in digestion technique resulted in different ratios of measured metals in soils of differing properties, such as pH, LOI and metal concentration. Any such trends with soil properties could under or over correct concentrations in particular soils types. Since some habitats and vegetation classes are associated with certain soils (e.g. Bogs with low pH, organic soils), this could lead to the erroneous identification of change in certain data stratifications. To investigate whether soil properties had the potential to bias result by differentially affecting extraction efficiency between CS in 1998 and 2007 methods, correlation plots were drawn between the predicted change between surveys and the potentially key soil properties of pH, LOI and metal concentration. For pH, 5 metals (Cd, Cu, Ni, Pb, Zn) showed no clear trend of change with soil acidity (***Fig. 7.1***). This suggested that the relative digestion efficiency of the different methods is not affected by this parameter. A small dependency of change in Cr concentration with pH was found indicating that association of habitats and vegetation classes with low pH could result in the incorrect identification of change, with errors relating to indications of increased change in low pH soil and reduced change in high pH soil. V showed a marked dependency of change on soil pH providing further support for exclusion of this metal from further analysis. Against LOI, all metals except V showed no clear trend of change (***Fig. 7.2***). Ideally, investigation of the effect of metal concentration on relative extraction efficiency would also have been tested, however, this analysis is affected by regression to the mean issues which means that the significant trends seen which indicates positive change at low concentrations and negative change at high concentrations are explained by statistical chance rather than a real concentration dependent effect. Overall the analysis of the effect of all testable soil properties supported the use of a single factor for back correction of the CS in 1998 measurements, with a slight caveat for soil Cr concentrations in respect of pH.

7.2.4 Reporting

Measured soil elemental concentrations for Li, Be, Al, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Rb, Se, Sr, Mo, Cd, Sb, Sn, Cs, Ba, W, Hg, Pb, U, P and S have been analysed to provide information on the state and in seven cases (Cd, Cr, Cu, Ni, Pb, V and Zn) change since CS in 1998. Data were analysed using the standard mixed model analysis appropriate to CS measurements. The statistical approach used for analysis for change involved bootstrapping which allows for non-normality in the data without the necessity of knowing details of actual distribution. As such it provides a more accurate measurement of significance. Annex F of Emmett *et al.* (2008) provides a background document describing this approach. The data in this report describes analysis of concentrations in CS in 2007 and changes since CS in 1998 for Cd, Cr, Cu, Ni, Pb, Zn in soils (0-15 cm) by Broad Habitat, Aggregate Vegetation Class (AVC) and soil LOI class:

Results are reported by three major categories for Great Britain and individual countries:

- Broad Habitat - the Broad Habitat classification consists of 27 habitats which account for the entire land surface of Great Britain, and the surrounding sea. Countryside Survey reports on 10 major terrestrial habitats.
- Aggregate Vegetation Class (AVC) – is a high level grouping of vegetation types produced from a quantitative hierarchical classification of the different plant species found in the original Countryside Survey sample plots.
- Soil organic matter (LOI) category - mineral (0-8% LOI; 0-44 g C kg^{-1}), humus-mineral (8 – 30% LOI ; 44-165 g C kg^{-1}), organo-mineral (30 – 60% LOI; 165-330 g C kg^{-1}) and organic (60 – 100%; > 330 g C kg^{-1}).

Analysis of concentrations by Broad Habitat class and soil type is also briefly reported for As, Mn, Se, Co, Hg, Mo, Al and Ti. Significant results relate to statistical significance with their ecological and policy relevance highlighted where appropriate.

Soil Arsenic (As) levels were interpolated using median indicator kriging to predict the probability of a threshold value of As concentration (8.07 mg/kg) being exceeded. A probability of 1 or above indicates that the data exceeds the specified threshold value at that location. This method of spatial interpolation is particularly suited to interpreting heavy metals, where point values can have large point scale variability, rendering ordinary kriging unsuitable. Data was interpolated onto a 1 km UK grid. The change for soil Cu was mapped using kriging to interpolate between the Countryside Survey sample points. Routine checking of data for outliers was conducted and the working data set was transformed using a normal score procedure to obtain a Gaussian distribution. The data were then interpolated on a 1km UK grid using ordinary kriging and finally, the kriged data were back-transformed to produce an interpolated map of % Cu change.

7.3 Results

7.3.1 Repeat measured metals comparison of CS data in 1998 and 2007

Cadmium

The mean concentration of Cd measured in GB soils collected in 2007 was 0.404 mg/kg. This compares with an mean concentration of 0.417 mg/kg measured in soil sample for CS in 1998 (***Table 7.3, Fig. 7.3***). This represents a non-significant change in measured Cd concentration of 0.013 mg/kg between surveys. Stratification of the data indicated that significant changes in soil Cd concentrations were not found in any Broad Habitat, although it was notable that four habitats that are associated with minimal management, namely Coniferous Woodland, Acid Grassland, Dwarf Shrub Heath and Fen, Marsh and Swamp showed relatively large, non-significant decreases in soil Cd concentration (in the region of 0.05 mg/kg magnitude). In contrast habitats associated with more intensive management such as Arable and Horticulture and Improved Grassland showed smaller changes, represented by a decline of 0.003 mg/kg and increase of 0.029 mg/kg respectively. Bog habitats also showed a small non-significant increase in measured soil Cd. Stratification by AVC indicated a significant reduction in measured soil Cd concentrations in Heath and Bog. Here mean measured concentrations reduced to 0.399 mg/kg in 2007 from a mean of 0.475 mg/kg in 1998. Significant change was not found for any other AVC. Stratification by soil LOI category indicated no significant change in Cd concentrations in Mineral, Humus mineral and Organic soils. In Organo-mineral soils, a significant decrease of 0.309 mg/kg was found in 2007 when compared to 1998 values. This category of soils is, however, represented by only a relatively small number of samples in the repeat sample dataset for Cd which may be a contributing factor towards the observed change for this LOI class.

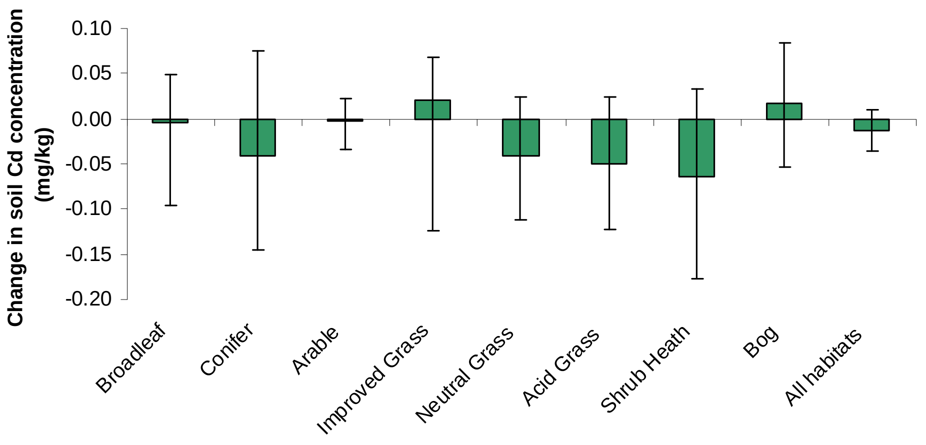
Table 7.4: Changes in concentration of Cd (mg/kg) in soils (0-15 cm depth) within a) Broad Habitats, b) Aggregate Vegetation Classes and c) Soil LOI categories across Great Britain. Arrows denote a significant change ($p<0.05$) in the direction shown.

a) Great Britain - Broad Habitats			
	Soil Cd concentration (mg/kg)		Direction of significant changes
Broad Habitat	1998	2007	1998-2007
Broadleaved, Mixed and Yew Woodland	0.413	0.418	
Coniferous Woodland	0.308	0.256	
Arable and Horticulture	0.355	0.352	
Improved Grassland	0.389	0.418	
Neutral Grassland	0.458	0.416	
Acid Grassland	0.458	0.404	
Dwarf Shrub Heath	0.457	0.392	
Fen, Marsh and Swamp	0.553	0.42	
Bog	0.631	0.646	
All habitat types	0.417	0.404	

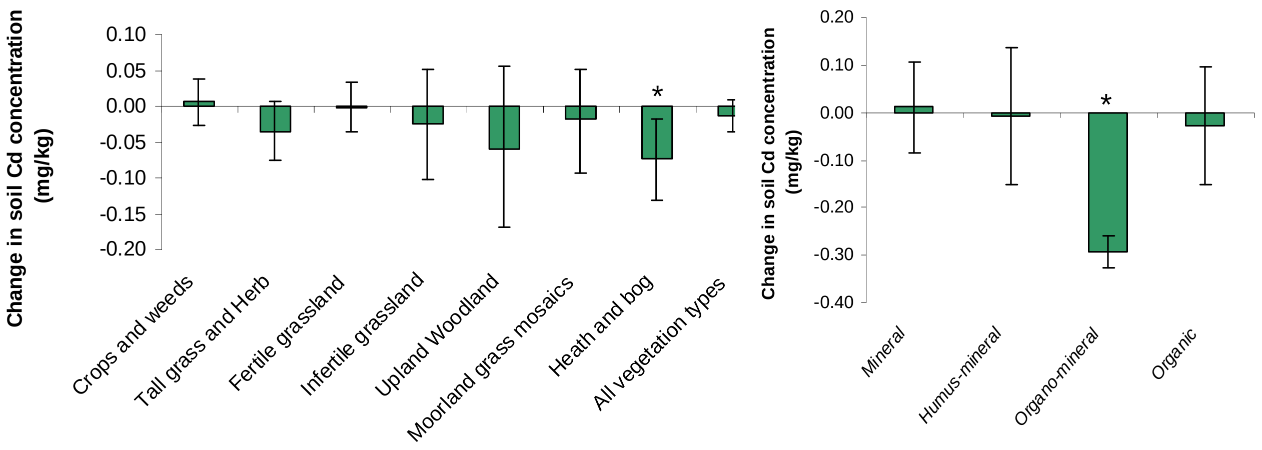
b) Great Britain - Aggregate Vegetation Class			
	Soil Cd concentration (mg/kg)		Direction of significant changes
AVC	1998	2007	1998-2007
Crops and weeds	0.355	0.359	
Tall grass and Herb	0.447	0.409	
Fertile grassland	0.367	0.365	
Infertile grassland	0.475	0.446	
Lowland woodland	0.576	0.612	
Upland Woodland	0.269	0.197	
Moorland grass mosaics	0.405	0.376	
Heath and bog	0.475	0.399	↓
All vegetation types	0.417	0.404	

c) Great Britain - Soil LOI Category			
	Soil Cd concentration (mg/kg)		Direction of significant changes
Soil LOI category	1998	2007	1998-2007
Mineral	0.32	0.332	
Humus-mineral	0.421	0.412	
Organo-mineral	0.557	0.246	↓
Organic	0.483	0.452	

Figure 7.3: Changes (+/- 95% CIs) in measured soil Cd concentration in soils (0-15 cm depth) within a) Broad Habitats, b) Aggregate Vegetation Classes and c) Soil LOI categories across Great Britain. Standard errors are indicated. Significant differences * p < 0.05, ** p < 0.01, *** p < 0.001 are shown.



a) Broad Habitats



b) Aggregate vegetation class

c) LOI categories

The mean concentration of Cr in GB soils was 21.3 mg/kg in CS in 2007 compared to the mean of 22.4 mg/kg in 1998 (***Table 7.5, Fig. 7.4***). This represents a non-significant decrease of 1.1 mg/kg. Stratification of the data to assess change in measured Cr by Broad Habitats indicated significant reductions in soil Cr concentrations between surveys in Broadleaved Woodland, Arable and Horticulture and Improved and Neutral Grasslands. In contrast in Bogs there was a significant increased in measured soil Cr. This increase was, however, from a low baseline level as Cr concentrations in Bog were lower than in any other habitat in both surveys (4.6 mg/kg in 1998 and 7.6 mg/kg in 2007). In other Broad Habitats, observed changes were non-significant, with Coniferous Woodland, Dwarf Shrub Heath and Fen, Marsh and Swamp all showing small non-significant increases in mean measured Cr concentration. Stratification by AVC partly reflected the trends seen within the Broad Habitats. Significant decreases in measured Cr concentrations were found in Crop and Weed and Fertile Grassland. Non-significant decreases were found in Tall Grass and Herb and Infertile Grassland. In contrast, a significant increase in measured soil Cr was found in Heath and Bog soils and non-significant increases in Upland Woodland and Moorland Grass Mosaic. Stratification by soil LOI category indicated a significant decrease in measured Cr concentrations in Mineral and Humus-mineral soils and a significant increase in Organic soils.

Table 7.5: Changes in concentration of Cr (mg/kg) in soils (0-15 cm depth) within a) Broad Habitats, b) Aggregate Vegetation Classes and c) Soil LOI categories across Great Britain. Arrows denote a significant change ($p<0.05$) in the direction shown.

a) Great Britain - Broad Habitats

	Soil Cr concentration (mg/kg)		Direction of significant changes
Broad Habitat	1998	2007	1998-2007
Broadleaved, Mixed and Yew Woodland	22.7	19.5	↓
Coniferous Woodland	12.8	13.9	
Arable and Horticulture	29.5	25.4	↓
Improved Grassland	28.2	26.4	↓
Neutral Grassland	27.6	23.9	↓
Acid Grassland	16.9	19.9	
Dwarf Shrub Heath	11	18.6	
Fen, Marsh and Swamp	20.8	21.6	
Bog	4.6	7.6	↑
All habitat types	22.4	21.3	

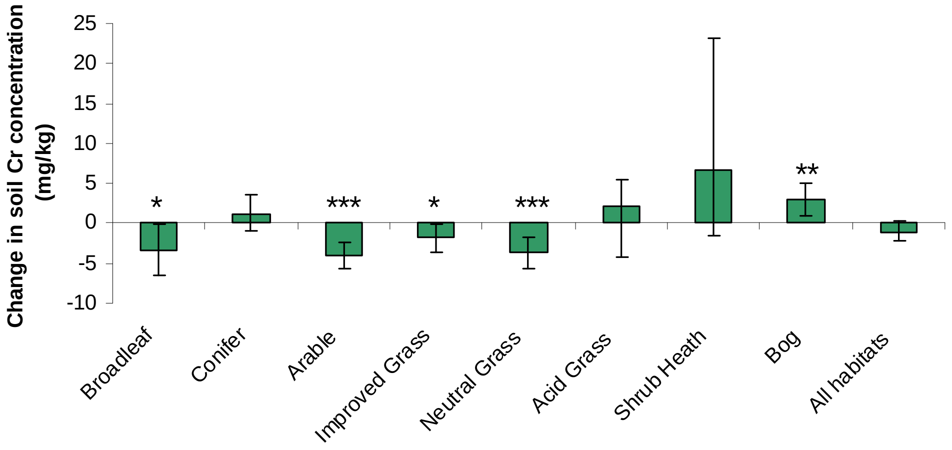
b) Great Britain - Aggregate Vegetation Class

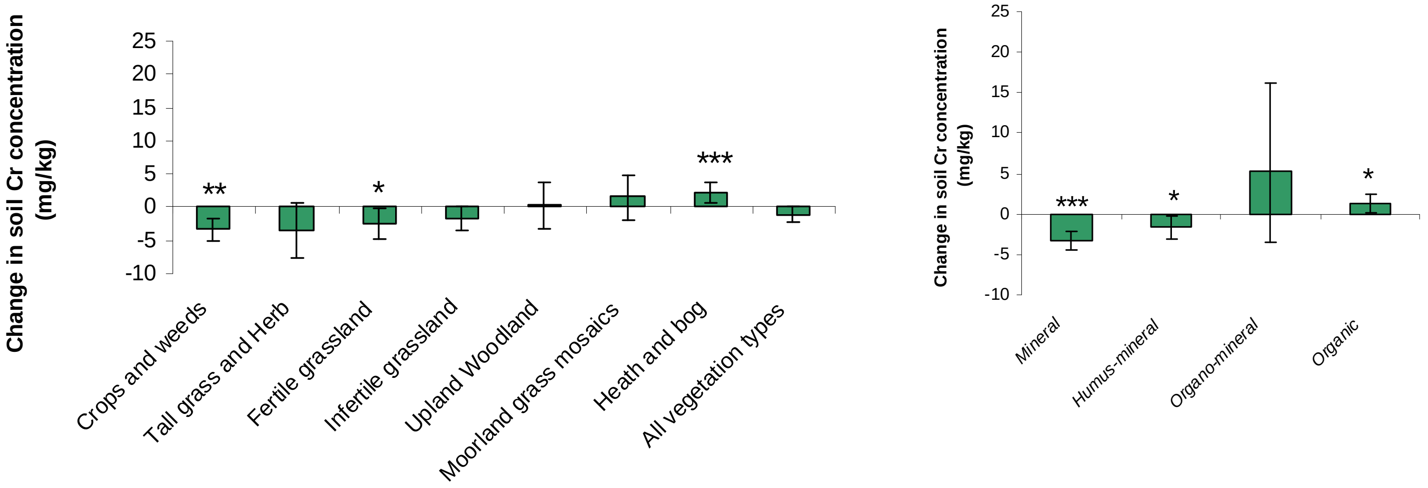
	Soil Cr concentration (mg/kg)		Direction of significant changes
AVC	1998	2007	1998-2007
Crops and weeds	29.5	26.1	↓
Tall grass and Herb	32.1	28.8	
Fertile grassland	28.6	26.2	↓
Infertile grassland	27	25.3	
Upland Woodland	23.2	23.7	
Moorland grass mosaics	15.7	17.3	
Heath and bog	4.8	7.1	↑
All vegetation types	22.4	21.3	

c) Great Britain - Soil LOI Category

	Soil Cr concentration (mg/kg)		Direction of significant changes
Soil LOI category	1998	2007	1998-2007
Mineral	26.8	23.6	↓
Humus-mineral	28	26.4	↓
Organo-mineral	18.3	24.7	↑
Organic	4.1	5.3	

Figure 7.4 Changes (+/- 95% CIs) in measured soil Cr concentration in soils (0-15 cm depth) within a) Broad Habitats, b) Aggregate Vegetation Classes and c) Soil LOI categories across Great Britain. Standard errors are indicated. Significant differences * p < 0.05, ** p < 0.01, *** p < 0.001 are shown.


a) Broad Habitats


b) Aggregate vegetation class

c) LOI categories

Copper

The mean concentration of Cu in GB soils analysed in CS in 2007 was 18.6 mg/kg (***Table 7.6, Fig. 7.5***). This is higher than the mean concentration of 16.6 mg/kg measured in 1998. This represents a statistically significant increase in soil Cu concentrations of 2 mg/kg between surveys. Stratification of the data to analyse change by Broad Habitats indicated that the increase in Cu concentration detected in the GB wide soil dataset was evident in all Broad Habitats, with the magnitude of change ranging from 0.2 mg/kg in Arable and Horticulture soils to 6 mg/kg in Dwarf Shrub Heath. In 3 of the 9 Broad Habitats, the increase in soil Cu was statistically significant. These were Improved Grassland, Dwarf Shrub Heath and Bogs which showed changes in measured soil Cu concentrations of 2.6, 6 and 4.1 mg/kg respectively. Stratification by AVC indicated an increase in soil Cu concentrations in all vegetation types except for Tall Grass and Herb and Upland Woodland for which small non-significant decreases were found. Three AVC categories showed significant increases in measured soil Cu. There were Fertile Grassland, Moorland Grass Mosaic and Heath and Bog, within which increases were 4.1, 5 and 3.3 mg/kg respectively. Analysis by soil LOI category indicated an increase of between 1.7 and 3.3 mg/kg for the four soil type stratifications. The measured increases were significant for 3 out of 4 categories, namely the Mineral, Humus-mineral and Organic soils.

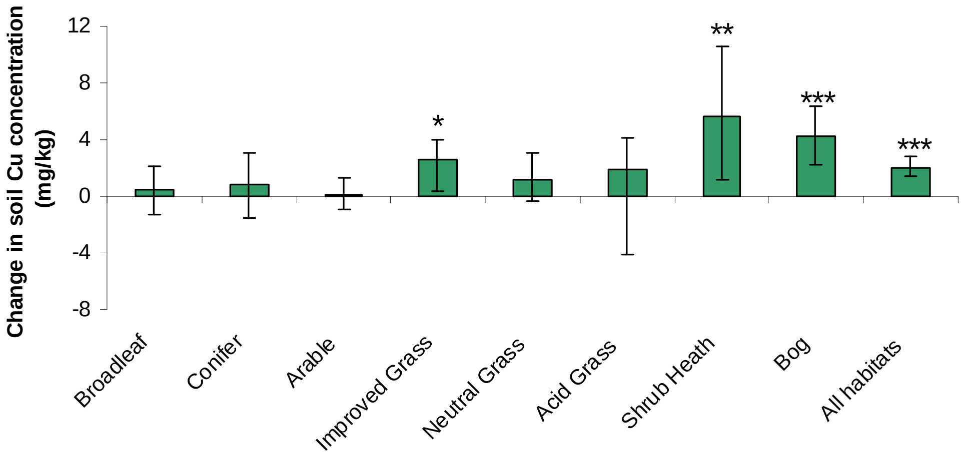
Table 7.6: Changes in concentration of Cu (mg/kg) in soils (0-15 cm depth) within a) Broad Habitats, b) Aggregate Vegetation Classes and c) Soil LOI categories across Great Britain. Arrows denote a significant change ($p<0.05$) in the direction shown.

a) Great Britain - Broad Habitats			
	Soil Cu concentration (mg/kg)		Direction of significant changes
Broad Habitat	1998	2007	1998-2007
Broadleaved, Mixed and Yew Woodland	25.9	26.3	
Coniferous Woodland	9.2	10.2	
Arable and Horticulture	20.5	20.7	
Improved Grassland	16.9	19.5	↑
Neutral Grassland	22.6	23.7	
Acid Grassland	12.4	14.7	
Dwarf Shrub Heath	10	16	↑
Fen, Marsh and Swamp	17.2	19.1	
Bog	6.9	11	↑
All habitat types	16.6	18.6	↑

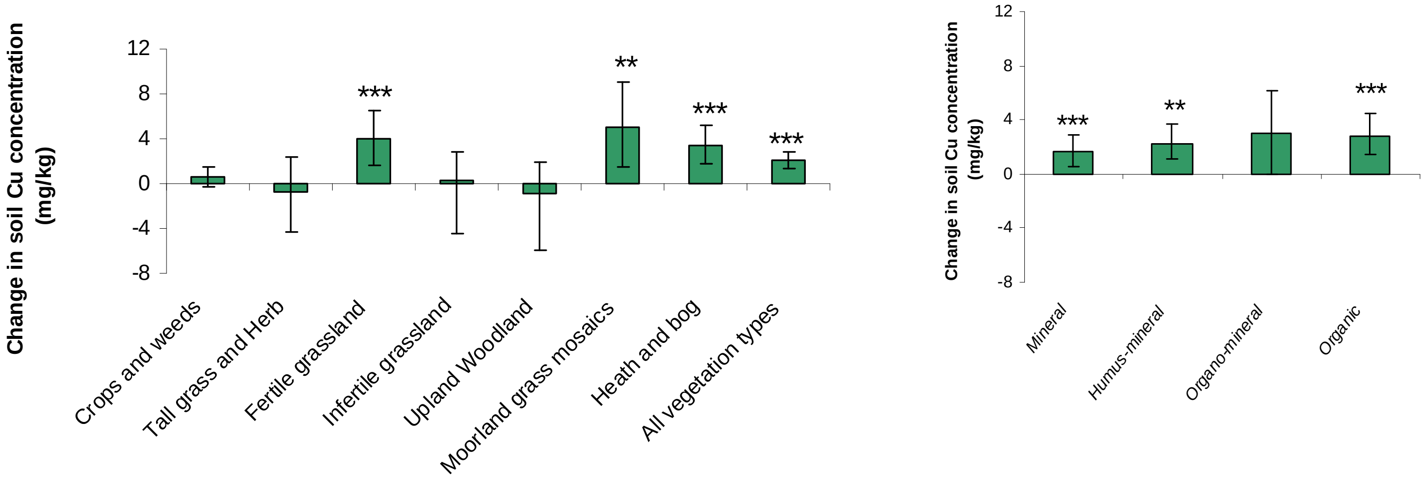
b) Great Britain - Aggregate Vegetation Class			
	Soil Cu concentration (mg/kg)		Direction of significant changes
AVC	1998	2007	1998-2007
Crops and weeds	19.4	20	
Tall grass and Herb	26.6	25.8	
Fertile grassland	19.8	23.9	↑
Infertile grassland	18.9	20.2	
Lowland wooded	34.9	36.8	
Upland Woodland	13.3	12.4	
Moorland grass mosaics	10.9	15.9	↑
Heath and bog	7.3	10.6	↑
All vegetation types	16.6	19	↑

c) Great Britain - Soil LOI Category			
	Soil Cu concentration (mg/kg)		Direction of significant changes
Soil LOI category	1998	2007	1998-2007
Mineral	17.8	19.5	↑
Humus-mineral	19.8	22.1	↑
Organo-mineral	16.1	19.5	
Organic	7.4	10.3	↑

Figure 7.5: Changes (+/- 95% CIs) in measured soil Cu concentration in soils (0-15 cm depth) within a) Broad Habitats, b) Aggregate Vegetation Classes and c) Soil LOI categories across Great Britain. Standard errors are indicated. Significant differences * p < 0.05, ** p < 0.01, *** p < 0.001 are shown.



a) Broad Habitats



b) Aggregate vegetation class

c) LOI categories

The mean concentration of Ni in GB soils collected and analysed in the 2007 survey was 18 mg/kg (***Table 7.7, Fig. 7.6***). This is slightly, although not significantly, lower than the mean measured concentration in 1998 of 18.4 mg/kg. Within the different Broad Habitat categories, a statistically significant decrease in soil Ni was found in 3. These were Broadleaved Woodland, where concentrations fell by 2 mg/kg and Arable and Horticulture, where concentrations reduced by 1.8 mg/kg and Neutral Grassland, where a 2.1 mg/kg decrease were found. There was one habitat where measured soil Ni concentrations significantly increased between surveys. This was Bog, within which mean measured soil Ni concentrations increased 4.1 mg/kg. Analysis by AVC indicated significant change of measured Ni concentrations in Crop and Weed only. Here a significant reduction in measured concentrations of 1.7 mg/kg was found. Analysis by soil LOI category indicated no significant change across any of the four soil classes.

Table 7.7: Changes in concentration of Ni (mg/kg) in soils (0-15 cm depth) within a) Broad Habitats, b) Aggregate Vegetation Classes and c) Soil LOI categories across Great Britain. Arrows denote a significant change ($p<0.05$) in the direction shown.

a) Great Britain - Broad Habitats

	Soil Ni concentration (mg/kg)		Direction of significant changes
Broad Habitat	1998	2007	1998-2007
Broadleaved, Mixed and Yew Woodland	17.9	15.9	↓
Coniferous Woodland	9	9.9	
Arable and Horticulture	21.9	20.1	↓
Improved Grassland	16.9	19.5	
Neutral Grassland	22.6	20.5	↓
Dwarf Shrub Heath	10.2	16.0	
Fen, Marsh and Swamp	17.2	19.1	
Bog	6.9	11.0	↑
All habitat types	18.4	18	

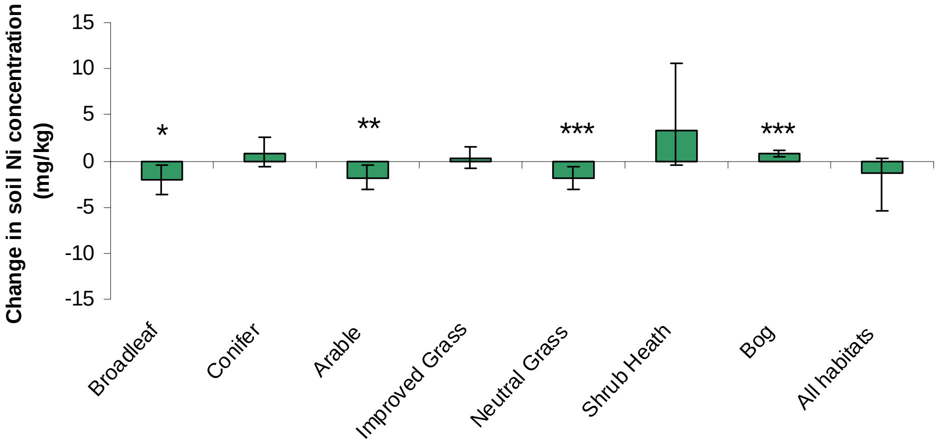
b) Great Britain - Aggregate Vegetation Class

	Soil Ni concentration (mg/kg)		Direction of significant changes
AVC	1998	2007	1998-2007
Crops and weeds	21.6	19.9	↓
Tall grass and Herb	23	22.8	
Fertile grassland	19.5	19.4	
Infertile grassland	20.5	19.3	
Lowland wooded	18.4	18	
Upland Woodland	14.3	14.8	
Moorland grass mosaics	25	24	
Heath and bog	7.0	7.4	
All vegetation types	18.4	18	

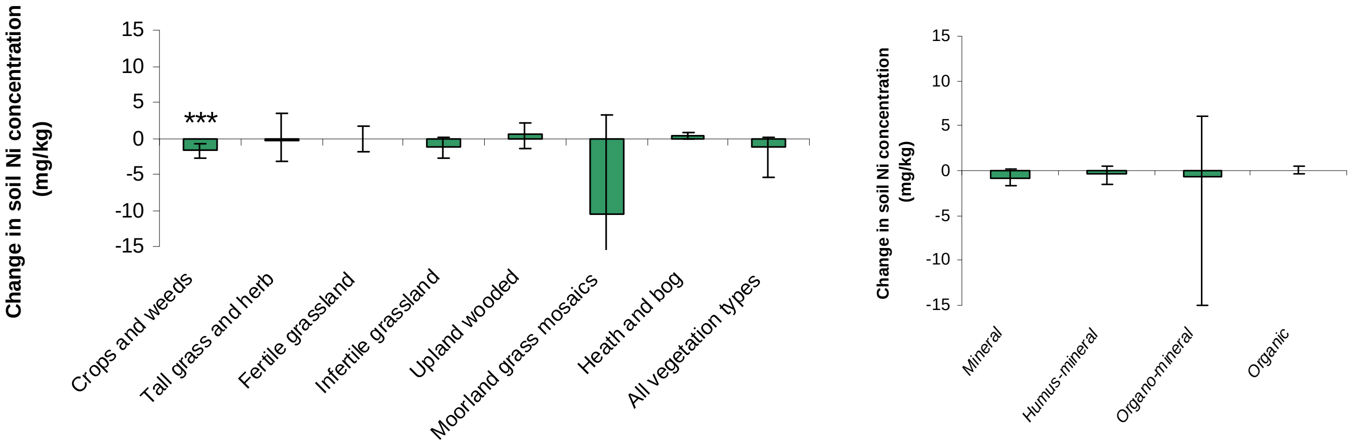
c) Great Britain - Soil LOI Category

	Soil Ni concentration (mg/kg)		Direction of significant
Soil LOI category	1998	2007	1998-2007
Mineral	19.7	18.9	
Humus-mineral	19.5	19.1	
Organo-mineral	24.9	25.3	
Organic	3.5	3.5	

Figure 7.6: Changes (+/- 95% CIs) in measured soil Ni concentration in soils (0-15 cm depth) within a) Broad Habitats, b) Aggregate Vegetation Classes and c) Soil LOI categories across Great Britain. Standard errors are indicated. Significant differences * p < 0.05, ** p < 0.01, *** p < 0.001 are shown.



a) Broad Habitats



b) Aggregate vegetation class

c) LOI categories

Lead

The mean measured concentration of Pb in GB soils in 2007 was 80.4 mg/kg (***Table 7.8, Fig. 7.7***). This is slightly, although not significantly, lower than the measured mean concentration of 82.5 mg/kg found in 1998. Stratification of the data by Broad Habitat indicated that there was an increase of between 0.4 and 20.4 mg/kg in 4 of 8 habitats. In two habitats, namely Improved Grassland and Dwarf Shrub Heath, this increase was statistically significant. The remaining habitats showed non-significant decreases in measured soil Pb concentrations ranging from 1.7 mg/k in Fen, Marsh and Swamp to 45.5 mg/kg in Acid Grassland. When data was analysed by AVC, no significant changes in soil Pb concentration were found for any category. Similarly stratification of the data by Soil LOI class did not highlight significant changes in measured soil Pb concentration between different soil types.

Table 7.8: Changes in concentration of Pb (mg/kg) in soils (0-15 cm depth) within a) Broad Habitats, b) Aggregate Vegetation Classes and c) Soil LOI categories across Great Britain. Arrows denote a significant change ($p<0.05$) in the direction shown.

a) Great Britain - Broad Habitats

	Soil Pb concentration (mg/kg)		Direction of significant changes
Broad Habitat	1998	2007	1998-2007
Coniferous Woodland	81.6	78.2	
Arable and Horticulture	41.5	41.9	
Improved Grassland	55	66.4	↑
Neutral Grassland	60.9	52.6	
Acid Grassland	118.8	76.3	
Dwarf Shrub Heath	67.9	88.3	↑
Fen, Marsh and Swamp	64.2	62.5	
Bog	56.2	59.2	
All habitat types	82.5	80.4	

b) Great Britain - Aggregate Vegetation Class

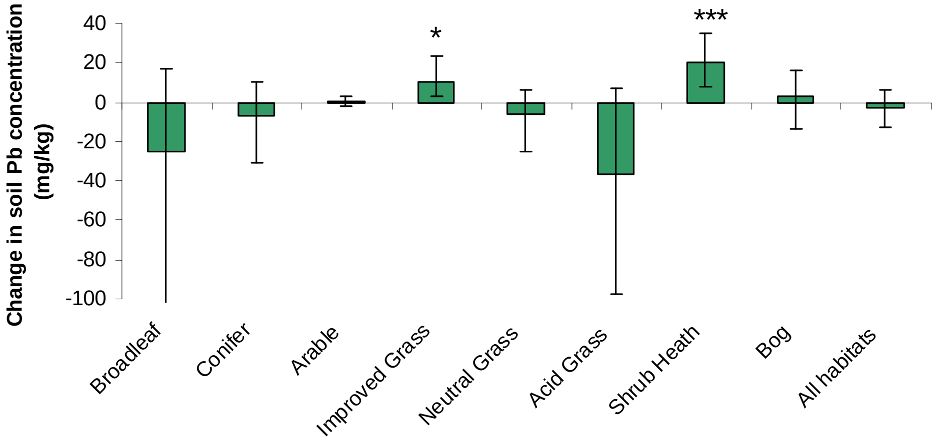
	Soil Pb concentration (mg/kg)		Direction of significant changes
AVC	1998	2007	1998-2007
Crops and weeds	44.9	45.4	
Tall grass and Herb	63.8	61.4	
Fertile grassland	56.0	61.7	
Infertile grassland	62.7	58.9	
Upland Woodland	85.3	78.0	
Moorland grass mosaics	88.7	82.9	
Heath and bog	70.4	70.5	
All vegetation types	82.5	80.4	

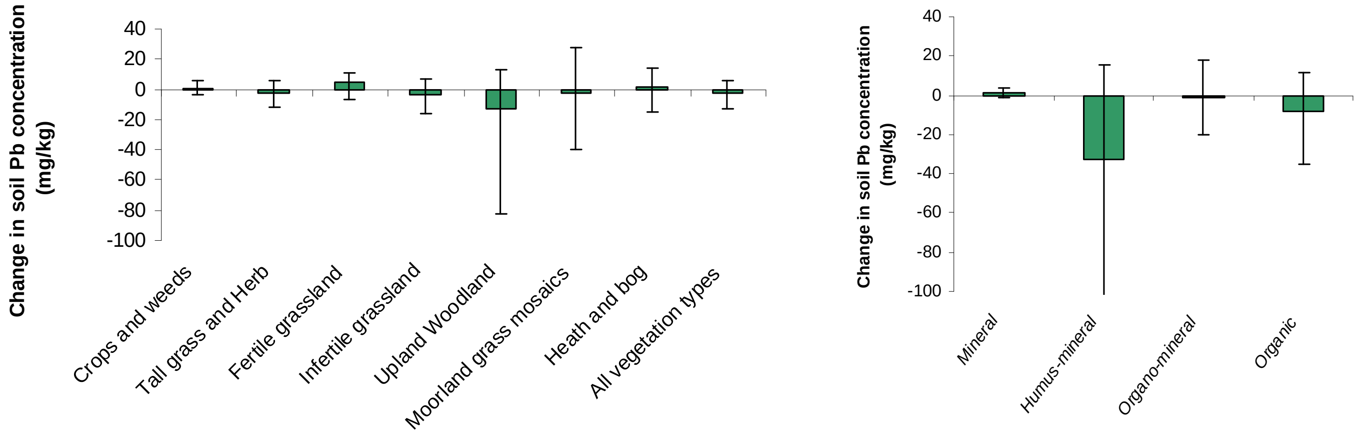
c) Great Britain - Soil LOI Category

	Soil Pb concentration (mg/kg)		Direction of significant changes
Soil LOI category	1998	2007	1998-2007
Mineral	41.3	42.6	
Humus-mineral	129.5	126.9	
Organo-mineral	99.7	98.5	
Organic	75.2	68.2	

Figure 7.7: Changes (+/- 95% CIs) in measured soil Pb concentration in soils (0-15 cm depth) within a) Broad Habitats, b) Aggregate Vegetation Classes and c) Soil LOI categories across Great Britain. Standard errors are indicated. Significant differences * p < 0.05, ** p < 0.01, *** p < 0.001 are shown.

a) Broad Habitats





b) Aggregate vegetation class

c) LOI categories

Zinc

The mean concentration of Zn in GB soils in CS in 2007 was 77.3 mg/kg (***Table 7.9, Fig. 7.8***). This is lower than the mean concentration of 80.4 mg/kg found in 1998. This reduction of 3.1 mg/kg in soil Zn in GB is not statistically significant. Stratification of the data to analyse change in soil Zn concentration by Broad Habitat indicated that mean concentration were lower in 2007 than in 1998 in 7 of 10 habitats. This reduction in soil Zn was significant in two habitats. These were Arable and Horticulture in which concentration fell on average by 5.7 mg/kg and Neutral Grassland in which concentrations fell by 10.4 mg/kg. A significant increase in soil Zn concentration of 7.2 mg/kg was found in Bog habitats. All other changes in measured soil Zn by Broad Habitats were not significant. When data was analysed by AVC, no significant changes in soil Zn concentration were indicated for any vegetation class. Stratification of the data by LOI class also failed to identify significant changes in measured Zn between soil types.

Table 7.9: Changes in concentration of Zn (mg/kg) in soils (0-15 cm depth) within a) Broad Habitats, b) Aggregate Vegetation Classes and c) Soil LOI categories across Great Britain. Arrows denote a significant change (p<0.05) in the direction shown.

a) Great Britain - Broad Habitats

	Soil Zn concentration (mg/kg)		Direction of significant changes
Broad Habitat	1998	2007	1998-2007
Broadleaved, Mixed and Yew Woodland	86.4	85.7	
Coniferous Woodland	44.6	48.5	
Arable and Horticulture	90.1	84.4	↓
Improved Grassland	107.6	104.3	
Neutral Grassland	99.5	89.1	↓
Acid Grassland	42.2	43.9	
Bracken	50.7	39.9	
Dwarf Shrub Heath	40.7	38.9	
Fen, Marsh and Swamp	68.2	58.3	
Bog	48.5	57.7	↑
All habitat types	80.4	77.3	

b) Great Britain - Aggregate Vegetation Class

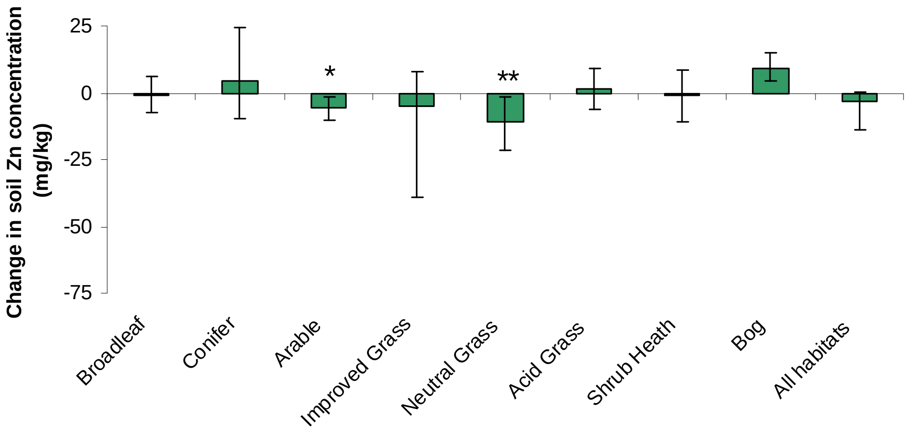
	Soil Zn concentration (mg/kg)		Direction of significant changes
AVC	1998	2007	1998-2007
Crops and weeds	94.3	91.9	
Tall grass and Herb	117	105.5	
Fertile grassland	103.3	102.4	
Infertile grassland	106.1	77.6	
Lowland woodland	104.6	108.7	
Upland Woodland	51.3	48.2	
Moorland grass mosaics	45	43.3	
Heath and bog	35.7	36.3	
All vegetation types	80.4	77	

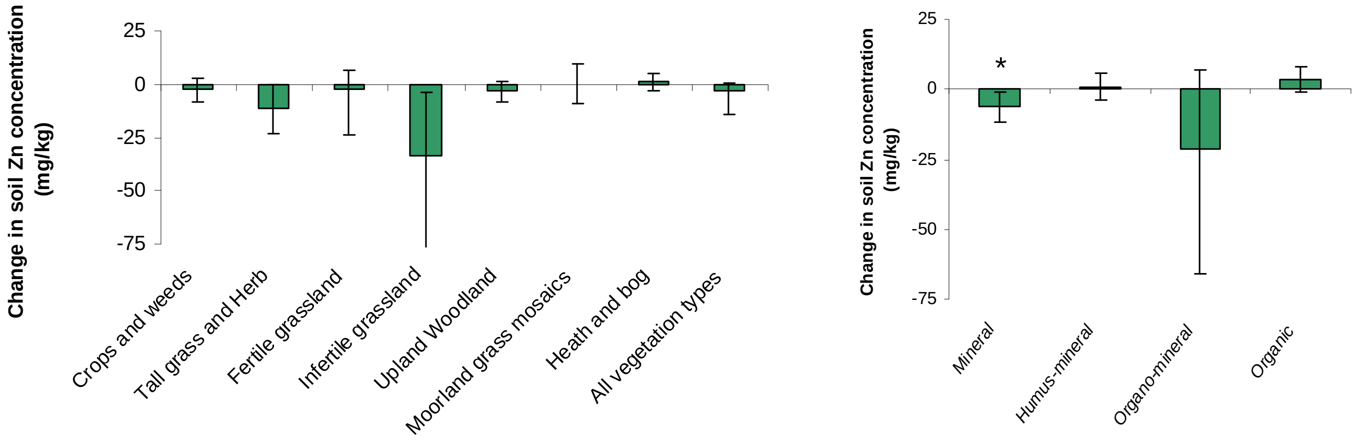
c) Great Britain - Soil LOI Category

	Soil Zn concentration (mg/kg)		Direction of significant changes
Soil LOI category	1998	2007	1998-2007
Mineral	88.5	82.4	
Humus-mineral	100	100.6	
Organo-mineral	61	35.7	
Organic	34.2	37.6	

Figure 7.8: Changes (+/- 95% CIs) in measured soil Zn concentration in soils (0-15 cm depth) within a) Broad Habitats, b) Aggregate Vegetation Classes and c) Soil LOI categories across Great Britain. Standard errors are indicated. Significant differences * p < 0.05, ** p < 0.01, *** p < 0.001 are shown.

a) Broad Habitats





b) Aggregate vegetation class

c) LOI categories

7.3.2 *Metals measured only in CS in 2007*

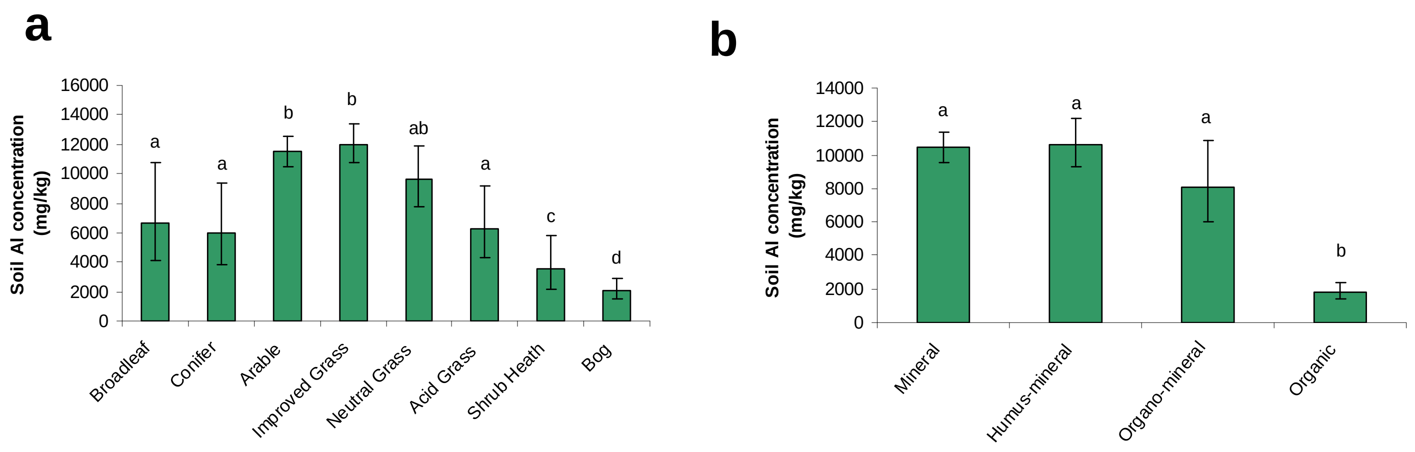
Use of a combined ICP-OES approach allowed extension of the suite of measured metal concentrations beyond the initial set of seven metals measured in 1998 to include a total assessment of the concentrations of 26 metal or metalloid elements (Li, Be, Al, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Rb, Se, Sr, Mo, Cd, Sb, Sn, Cs, Ba, W, Hg, Pb, U as well as Cd, Cr, Cu, Ni, Pb, V and Zn) in almost 500 GB soil samples. Seven of these single time point measured metals are reported here but the full dataset is available for download from the CS website. The analysis includes stratification of the data available for each chosen metal by Broad Habitat and Soil LOI category. The seven chosen metals and metalloids have been selected for initial assessment because they have a known toxicity to humans and wildlife and so have been of long-standing regulatory concern; because they are essential metals that can elicit both deficiency at low concentration and toxicity at high concentration; and / or because new application (fuel additive, nanomaterial) means that current commercial and consumer product uses are increasing. Specific reason for selection for each metal/metalloid are:.

- **Al is selected as it is common in soils and has been widely implicated in toxicity during acidification.**
- **As is selected as it is a known risk for food chain transfer to wildlife and humans.**
- **Mn is selected as it is widely used in an increasing number of commercial products.**
- **Hg is selected because it is the focus of the Defra Critical Loads metals project and also because no change has been detected in European Moss Surveys indicating continued deposition at historic rates.**
- **Mo is selected as it is essential and is currently one of the focus metals for EU wide metals risk assessment activities.**
- **Se is selected as it has a small "window of essentiality" meaning it is known to cause toxicity at high concentration, but and also to be deficient at low levels in soil.**
- **Ti is selected as it is of growing regulatory concern due to commercial uses including in nanoparticle forms.**

Aluminium

Concentrations of aluminium were higher than those of Cd, Cu, Cr, Ni, Pb, Zn, As, Mn, Hg, Mo, Se or Ti by at least a factor of ten and more than this in many cases. Within Broad Habitats concentration ranged from 2060 mg/kg in Bog to almost 12,000 mg/kg in Arable and Horticulture and Improved Grassland soils. Habitats that are associated with lowland areas on mineral soils, such as Improved and Neutral Grassland and Arable and Horticulture, contained significantly higher Al concentrations than habitats such as Dwarf Shrub Heath and Bog which are associated with upland areas on organic of organo-mineral soils (***Fig. 7.9***). The analysis by LOI indicates that Al concentrations in soils are significantly different in organic soils when compared to the three remaining soil categories. Since organic soils are most commonly found in habitats, such as Bog and Dwarf Shrub Heath, this suggests that the soil type associated with these habitats may have important influences on soil Al concentration. Particularly important are likely to be the lower pH of soils in upland habitats and also high rainfall rates found in these areas. Both of these factors can lead to greater metal mobility resulting in greater leaching losses.

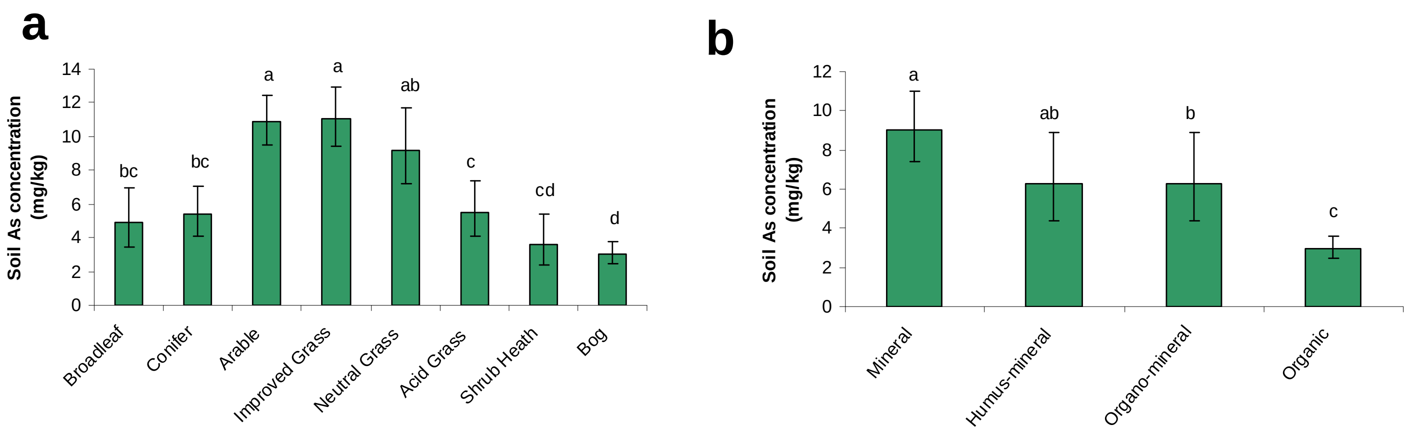
Figure 7.9: Measured soil Al concentration (+/- 95% CIs) in soils (0-15 cm depth) within a) Broad Habitats, b) Soil LOI categories across Great Britain. Columns not sharing the same letter are significantly different at $p < 0.05$ level.



Arsenic

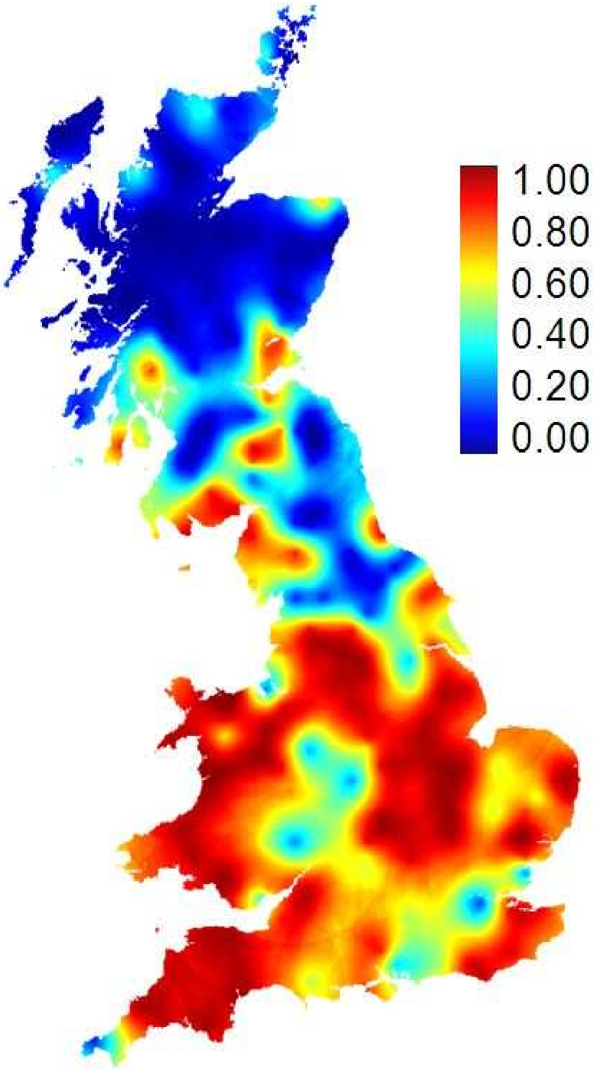
Concentrations of arsenic analysed by Broad Habitat ranged 3.02 mg/kg in Bog to 11.02mg/kg in soils under Improved Grassland (***Fig. 7.10***). When As concentration are compared across habitats, it is evident that the highest concentration, like those for Al, are found in Arable and Horticulture and Improved and Neutral Grasslands; Acid Grassland and Broadleaved and Coniferous Woodland soils were intermediate; while habitats associated with more remote and upland area, such as Bogs and Dwarf Shrub Heath soils contain significantly lower As concentration than soils in lowland agricultural habitats (***Fig. 7.10***). Analysis by soil LOI category indicated that soil As concentrations were significantly higher in mineral soils than in Organo-mineral and Organic soils (***Fig. 7.10***).

Figure 7.10: Measured soil As concentration (+/- 95% CIs) in soils (0-15 cm depth) within a) Broad Habitats, b) Soil LOI categories across Great Britain. Columns not sharing the same letter are significantly different at $p <$ 0.05 level.



Soil Arsenic (As) levels in GB soils measure in CS in 2007, were interpolated using median indicator kriging to predict the probability of exceeding the median value of the data set (8.07 mg/kg). The use of indicator kriging, rather than ordinary kriging and spatial interpolation, arises because of the type of data being analyzed. In the case of soil metals and metalloids the assumption of connectivity between sample points with extreme values in space is not necessarily valid. As a result, ordinary kriging, incorporating these extreme values provides erroneous interpolation, biased towards extremes. Indicator kriging provides a method of spatially interpreting the underlying patterns in the data without such a bias, interpolating the probability that the data falls above or below a given threshold. A probability of 1 or above indicates that the data exceeds the specified threshold value represented by the median concentration (As, 8.07 mg/kg) at that location. Data were interpolated in this manner onto a 1 km GB grid. Mapping of As concentration as the probability to exceed median values indicates highest probability of exceedance (i.e. high likelihood of high concentrations) in soil in the Midlands and south of England and Wales (***Fig. 7.11***). This spatial distribution of As reflects patterns in As concentration measured in previous soil and stream sediment surveys, such as the NSI soil metal survey and G-BASE. The higher frequency of above average soil As concentrations found in these regions can be linked to the known presence pf As rich Jurassic and Cretaceous rocks from which the surfaces soils are derived. Indeed areas of the south-west of England, notably in Devon and Cornwall, are well known for the prevalence of historic arsenic mining areas (e.g. in the Tamar valley).

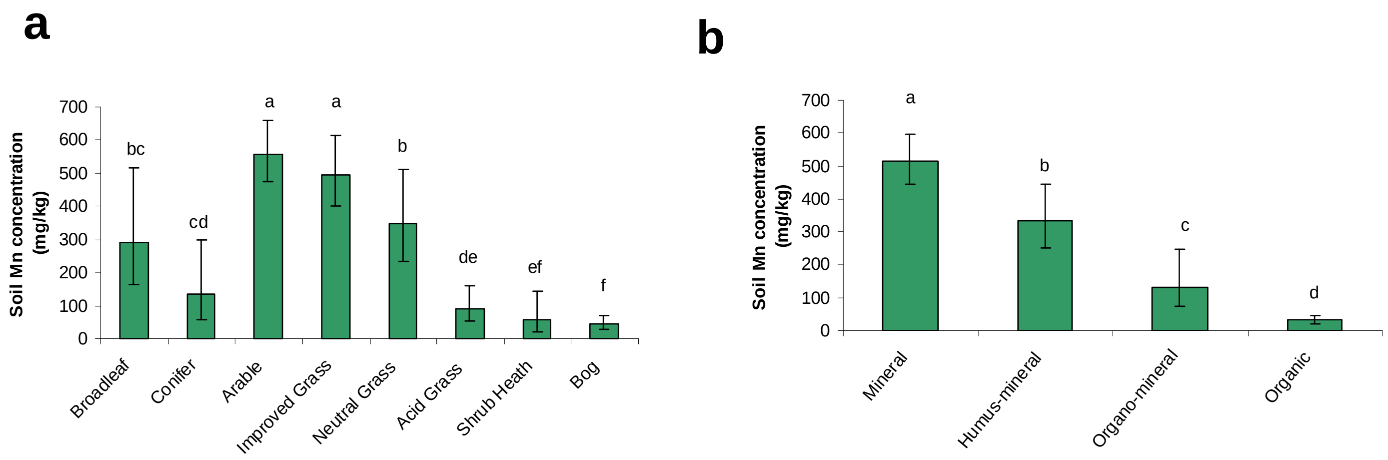
Figure 7.11: Map of probability that a plot exceeds the median value of 8.07 mg/Kg As in soils (0-15 cm) collected from across GB in CS in 2007 – value of one indicate guaranteed exceedance, values of 0 non exceedance



Manganese

Mean manganese concentrations varied between Broad Habitats by approximately an order of magnitude ranging from 46 mg/kg in Bog and 56.6 mg/kg in Dwarf Shrub Heath to 558 mg/kg and 495 mg/kg in the Arable and Horticulture and Improved Grassland soils. As for Al and As, highest Mn concentrations were found in habitat categories that are associated with lowland areas located principally on mineral soils. These include soils in Improved and Neutral Grassland and Arable and Horticulture habitats. Upland habitats located on acid organic soils, such as Bog, Dwarf Shrub Heath and also Acid Grassland showed the lowest Mn concentrations. Coniferous and Broadleaved Woodlands were intermediate. Analysis by LOI supported a role for soil type alone in determining the patterns of Mn concentration between Broad Habitats. A clear pattern of significant reduction in measured Mn concentrations was found in soil categories of increasing LOI (***Fig. 7.12***). This suggests that the soil characteristics in some habitats, such as the lower mineral soil content and typically lower pH values of Bog, Dwarf Shrub Heath and Acid Grassland habitats, coupled to high rainfall in the upland areas, may be important in explaining observed differences through their effects on leaching rates.

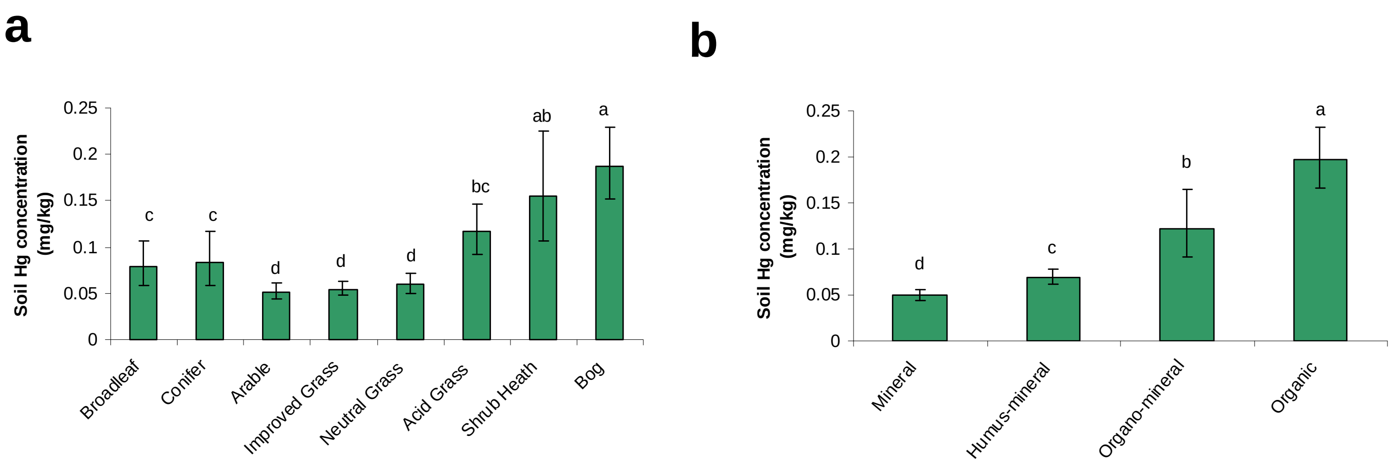
Figure 7.12: Measured soil Mn concentration (+/- 95% CIs) in soils (0-15 cm depth) within a) Broad Habitats, b) Soil LOI categories across Great Britain. Columns not sharing the same letter are significantly different at $p <$ 0.05 level.



Mercury

Mercury was the sole metal amongst the 13 discussed in detail in this chapter for which measured concentration frequently did not exceed the analytical limits of detection. Of the 414 samples successfully digested and analysed for Hg concentration 175 (42%) contained Hg concentrations that were below the detection limit of 0.067mg/kg. When correcting the low level unquantified samples to a value of half the analytical detection limit, in accordance with standard practice, measured Hg concentration between habitats ranged from 0.052 mg/kg in Arable and Horticulture soil to 0.187 in Bog. Stratification by Broad Habitat indicated a contrasting trend to Al, As and Mn for soil Hg. Thus, highest concentrations were found in Bogs, Dwarf Shrub Heath and Acid Grassland and lowest concentration in Arable and Horticulture and Improved and Neutral Grassland. Hg concentrations were also influence by soil LOI category, showing significant differences between all treatments, with highest values in organic soils (***Fig. 7.13***). At high concentrations, Hg is known to be toxic to biota and also to accumulate in food chains. High Hg concentrations have, for example, been detected in tissues of piscivorus species in the UK Predatory Bird Monitoring Scheme, suggesting that this may be an important exposure route, particularly for organic mercury. The presence of higher concentrations of Hg associated with habitats such as Acid Grassland, Dwarf Shrub Heath and Bog and with Organic soils indicates that the greatest potential for Hg exposure in wildlife is likely to occur in these, principally upland, areas.

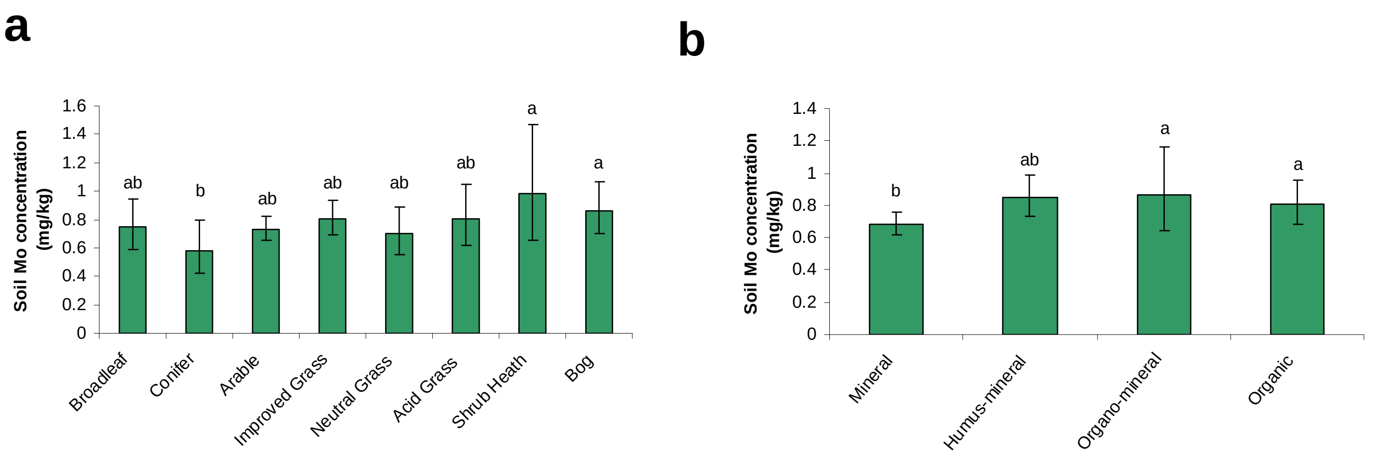
Figure 7.13: Measured soil Hg concentration (+/- 95% CIs) in soils (0-15 cm depth) within a) Broad Habitats, b) Soil LOI categories across Great Britain. Columns not sharing the same letter are significantly different at $p < 0.05$ level.



Molybdenum

Mean molybdenum concentrations ranged between Broad Habitats by less than a factor of two. Highest concentrations of 0.979 mg/kg were found in Dwarf Shrub Heath soils and lowest concentrations of 0.581 mg/kg in Coniferous Woodlands (***Fig. 7.14***). The difference in Mo concentration between these two Broad Habitats was significant. This was not the case for any other Broad Habitat pair except Coniferous Woodland and Bog. Stratification by LOI indicated that mineral soils contain significantly lower Mo concentration than either Organo-mineral or Organic soils. Difference in mean concentration were, however, actually rather small (maximum difference 0.2 mg/kg between Mineral and Humus-mineral soils).

Figure 7.14: Measured soil Mo concentration (+/- 95% CIs) in soils (0-15 cm depth) within a) Broad Habitats, b) Soil LOI categories across Great Britain. Columns not sharing the same letter are significantly different at $p < 0.05$ level.

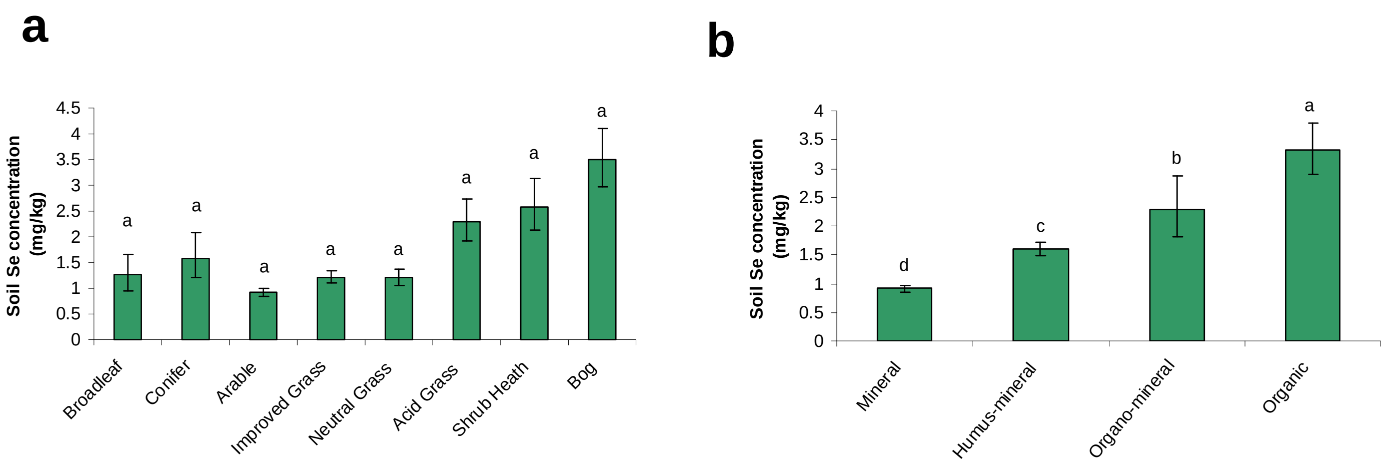


Selenium

Se is an essential trace element that is also toxic at high concentrations. Hence, it is often stated to have a small “window of essentiality” for environmental concentration within which neither deficiency or toxic would be anticipated. Measured mean Se concentrations in CS in 2007 soils differed between Broad Habitats by approximately a factor of 4. Highest concentrations were in habitats associated with low pH, organic rich upland soils such as Bog, Dwarf Shrub Heath and Acid Grassland. Lowest concentrations were in Arable and Horticulture, and Improved and Neutral Grassland soils (***Fig. 7.15***). Analysis by soil LOI stratification indicated significant differences in Se concentrations between all soils types, with highest Se concentration associated Organic soils and a clear trend for decreasing concentration in lower LOI soils.

Cases of Se toxicity have most frequently been associated with point source industrial release scenarios or the local consumption of vegetables grown on selenium-rich carbonaceous shale derived soils (as affected member of a rural Chinese population). Such exposure scenarios are not relevant to the GB situation, indicating that Se toxicity is unlikely to be a major national issue of concern. As well as high concentrations being toxic to humans, as well as other plant and animal species, Se can also affect plant growth and animal health as a result of deficiency. Again in China this has been linked both to effects of crop production and also to human disease (Wang and Gao, 1998). Currently no criteria exist that set a critical concentration for Se deficiency in soils. For plants growing on potentially Se deficient soils, it is clear that the value for deficiency will depend on both the plant species considered and also the effect of soil properties on Se bioavailability. Further for establishing a lower level for human food consumption and for animal (including livestock) health, the composition of the diet and the proportion that is grown on Se deficient soils is also an important factor, especially when a prominent portion of diet sourced locally. On the basis of published studies, probable concentrations for deficiency are likely to be in the range 0.1-0.25 mg/kg. In GB soils no plot contains Se levels below these concentrations. Taking a conservative value of 0.5 mg/kg as an indication of potentially deficient soil, only 8 of 414 plots (1.9%) contain soil Se level below this value. Hence it is unlikely that deficiency in soils Se concentration is a major factor that is influencing the nature of prevalent plant communities across GB.

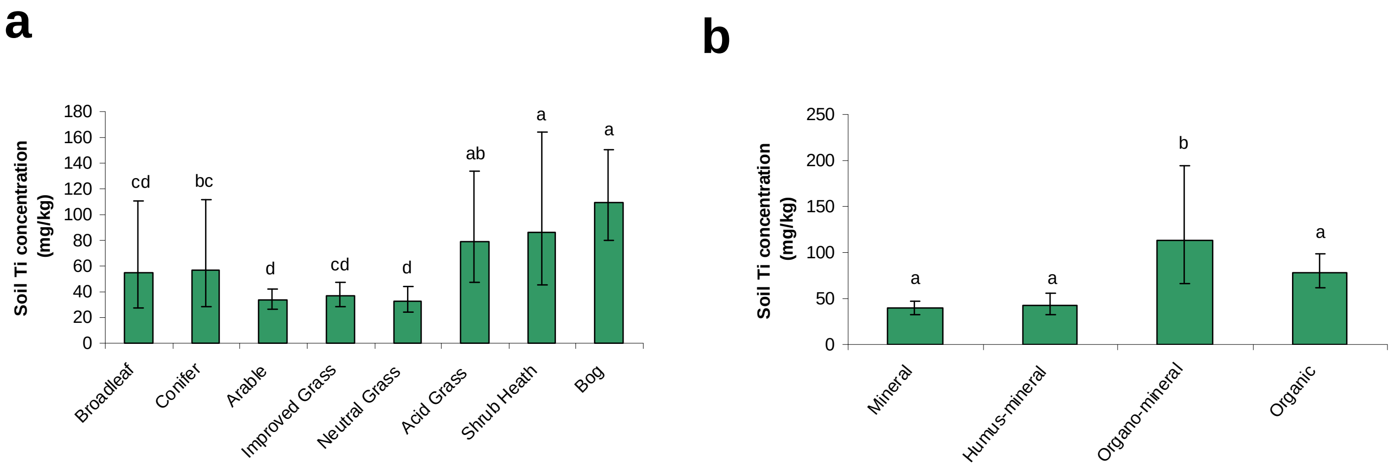
Figure 7.15: Measured soil Se concentration (+/- 95% CIs) in soils (0-15 cm depth) within a) Broad Habitats, b) Soil LOI categories across Great Britain. Columns not sharing the same letter are significantly different at p < 0.05 level.



Titanium

TiO_2 is currently one of the most widely used nanoparticle types in consumer products. Concerns about the potential effects of nanoparticle on human health and wildlife have resulted in a growing interest in the biogeochemistry of titanium. Particularly important is to establish baseline concentration of Ti in soil, waters and sediments since these provide a natural background against which any additional input of Ti in nanoparticle form would have to be detected. In GB soil, measured Ti concentrations ranged between Broad Habitats by approximately a factor of 3, from a highest concentration of 109 mg/kg in Bog soils to 32.5 mg/kg in Neutral Grassland (***Fig. 7.16***). Between Broad Habitats, soils from Bog, Dwarf Shrub Heath and Acid Grassland contained higher concentrations than Arable and Horticulture and Neutral and Improved Grassland, with Broadleaved and Coniferous Woodland intermediate. Stratification by LOI indicated that mineral soils contained significantly lower Ti concentration than Oragno-mineral soils. The analysis indicates a relatively high background level of Ti in GB soils (50-100 mg/kg) against which any future inputs of titanium must be detected.

Figure 7.16: Measured soil Ti concentration (+/- 95% CIs) in soils (0-15 cm depth) within a) Broad Habitats, b) Soil LOI categories across Great Britain. Columns not sharing the same letter are significantly different at p < 0.05 level.



7.4 Discussion and Policy Implications

A number of surveys have measured metal concentrations in soils and stream sediments collected from a network of sites within GB or constituent countries. The UK Soil and Herbage Survey conducted by the Environment Agency (EA) for England and Wales measured concentrations of 13 elements (Cd, Cr, Cu, Mn, Hg, Ni, Pb, Pt, Ti, V, Zn, Sn As, Zn) in soil and vegetation from 122 rural sites, 29 urban sites and 54 industrial sites across the UK (Ross *et al.*, 2007). Measurement of soil (015cm) trace element concentrations were accompanied by additional measurements of the concentration of organic pollutants including polychlorinated biphenyls; polycyclic aromatic hydrocarbons and polychlorinated dioxins and furans. Analysis of the data was conducted to assess mean concentration of measure trace pollutants and metals in soil according to Country (England, Scotland, Wales) and site location (rural, urban, industrial). All data from the UK Soil and Herbage Survey has been published. To date, however, the sampling and analysis campaign has not been repeated meaning that an assessment of change in trace element concentration is not possible within the dataset.

An extensive survey of metal concentration in UK soils has also been conducted within the framework of the National Soil Inventory (NSI) program. This study has reported on a range of properties of UK soils including total and extractable metal concentrations in over 6000 soil samples collected across England and Wales, with further data for Scotland available through the NSI Scotland Phase 1 and 2 projects. A set of detailed spatially resolved maps have been produced from this data which include maps of soil metal concentration (McGrath and Loveland, 1992). The Geochemical Baseline Survey of the Environment (G-BASE) which is coordinated by the British Geological Survey (BGS) is also a large scale and long running survey of stream water, stream sediment and soil chemistry that has measured metal concentrations in stream and soil samples (5-20 cm depth) collected at an average density of one sample every 1–2 km^2 of UK land surface (**www.bgs.ac.uk/gbase/home.html**). To date, G-BASE has been completed for all regions except the Southern third of England, with this area is scheduled for completion over the next decade.

Compared to the EA, NSI and BGS surveys, the soil component of Countryside Survey in 2007 has a spatial resolution for the trace metals comparable with that of the EA's UK Soils and Herbage survey. The Soil and Herbage survey included 205 sample sites, while CS has measurements for 256 squares, although within each square, 5 samples in CS in 1998 and 2 in CS in 2007 have been measured. The spatial resolution of CS is, however, below those of either the G-BASE or the NSI datasets which each comprise a much greater number of analysed samples. Compared to the other major soil and stream sediment survey conducted in the UK, CS is unique because sites are visited over a single season at time periods separated over a number of years (6-9 year intervals between surveys). Within the soil component of CS, samples have been collected on three occasions in survey years (1978, 1998, 2007) and trace metal concentrations measured in the surveys in 1998 and 2007. This means that CS has the unique ability to look for large scale change in soil properties including trace metal concentrations over time within GB top soils (0-15 cm). Despite the (relatively) sparse spatial resolution, CS soil metal analyses can nonetheless be a valuable addition to current knowledge on trace element concentrations in GB soils. In particular, because soil metal concentrations are not measured in isolation, but instead form part of a wider survey of the physical, chemical and biological characteristics of GB habitats, measurement of soil metal concentrations can be stratified and correlated according to a range of other measurement parameters.

Metal content of soil is derived from two main sources (Boruvka *et al.*, 2005) - either naturally from the geogenic weathering of base rock during soil formation (pedogenesis) or anthropogenically through point source or diffuse pollution and/or solid waste disposal (Merian *et al.*, 2004). There is therefore a need to consider both potential sources when assessing difference in metal concentration between habitats and also over time. In the absence of human inputs, it can be expected that the metal concentration of soils will reach a steady state which represents the balance of inputs derived from weathering and natural deposition (e.g. volcanic) and outputs due to leaching and vegetative off-take. Additional human associated inputs can result in an increase in soil metal concentrations because the increased fluxes to soils will mean that inputs exceed outputs, thereby allowing concentrations to rise. As soil concentrations start to increase due to, for example, human associated deposition, rates of leaching will begin to increase until eventually a new steady state at a higher soil metal concentration is reached - although this may take decades to hundreds of years, depending upon the metal. If inputs then reduce, long-term reductions in soil concentrations may be initiated as leaching rates exceed inputs.

Available evidence from the UK Heavy Metal Deposition Monitoring, herbarium studies and Europe-wide survey of metal concentration in moss samples suggests that currently the rates of aerial deposition of metals to soils peaked in the UK in the 1960-1970s and are now in steady decline (RoTAP 2010). Legislation on the concentrations of metals present in fertilisers (especially Cd), domestic and industrial sludges and other waste streams regularly recovered to land have also been effective in reducing input concentrations for a range of trace elements. Although input rates are likely to be decreasing, work within Defra supported projects to assess environmental risks of metals for UK soils still predict exceedances of estimated critical load for Cd and Pb in 9.6% and 6% of UK soil respectively (Hall *et al.*, 2006). Comparison of the concentrations of Cd, Cu, Pb and Zn measured in CS soil samples in 1998 also indicated that measured concentrations exceeded the soil pH and LOI corrected critical limits for these metals as developed by Lofts *et al.* (2004) within Defra funded projects to develop a critical loads approach for trace metals by at least a factor of 3 in 0%, 20.7%, 15.5% and 22.1% of soil samples for Cd, Cu, Pb and Zn respectively (Spurgeon *et al.*, 2008). These analyses suggest that soil metal concentrations in GB are elevated as a result of direct inputs and that risk to soil communities as a result of this metal loading cannot be excluded.

With inputs in potential decline, a key aim in CS was to see whether the trend for increasing soil surface metal concentration has been reversed to the point where leaching and other losses may exceed inputs and so measured soil metal concentrations may have started to decline at a rate detectable in the timeframe of successive Countryside Surveys. When looking for change between temporally separate surveys, it is important to consider the influence that any difference in survey methods may play, since differences in method may lead to potentially spurious indications of change. Unfortunately in the case of soil metal analysis within CS, a major change in the analytical procedure had to be implemented because of changes in the infrastructure available at the analytical laboratory. In particular, the hot plate reflux system used for the digestion of all soil in CS in 1998 was not available for the reanalysis in 2007. The alternative method used was microwave digestion. For both procedures the regent used was Aqua Regia. While use of the same reagent for digestion is an important consideration, it is also possible that the changes in the temperature and pressure condition during digestion may have an effect on digestion efficiency and on concentrations measured from similar samples. To investigate this, results for the standard reference material BCR CRM141R calcareous loam soil which was measured multiple times through the analysis programme of both surveys were compared to determine whether the different digestion methods used resulted in similar estimates of trace element concentration in the CRM. The CRM assessment was supported by a targeted reanalysis of 1998 collected soils using the 2007 method. The comparison of measured concentration in the CRM revealed that the two methods gave slightly different quantification for Cd, Cr, Cu, Ni, Pb, V and Zn concentrations (***Table 7.2***) and this was supported the results of the reanalysis of CS in 1998 soils (***Table 7.3***). Thus, to allow change analysis, a back correction of 1998 measurements was conducted to recalculate measured concentration for the 1998 soils to a predicted concentration that would be expected assuming analysis using the 2007 method. This was done by dividing 1998 measurements by the ratio of the 1998:2007 mean measured concentrations for the BCR CRM141R analyse. Checks that a single value for correction was applicable to all soils were conducted by plotting predicted change between surveys against both the LOI and pH measured in CS in 2007 soils. These plots indicated no clear trend for difference with LOI for 6 of 7 metals and no clear trend for 5 of 7 metals for pH. Exceptions were V which showed dependency of change on pH and LOI and Cr which showed slight dependency for pH.

With metal inputs to GB soils estimated to be falling, dynamic modelling within Defra funded projects on critical loads assessment has been used to estimate the potential residence times of some existing pollutant metals in UK soils. This has suggested that the metals will reside in soils for at least many decades even for relatively mobile metals (e.g. Cd, Zn) and possibly many millennia for metals that have a high affinity to soil organic matter (e.g. Cd, Pb) (Tipping *et al.*, 2006b). Extensive datasets on the rates of change of concentrations of metals in soils are currently, however, scarcely available against which to validate these model predictions. The analysis of change between back corrected 1998 data and measurements made in CS in 2007 outlined here can be used to provide initial insight into the rates of change of soil trace metal concentrations. Results indicated that generally only small scale changes in measured soil metal concentrations were found between survey years. Comparison of concentration indicated that a change in estimated 1998 and measured 2007 concentrations of greater than 10% were found in 6 of 21 stratification levels (Broad Habitat, AVC, soil LOI Category) for Cd, 9 of 21 for Cr, 13 of 21 for Cu, 3 of 20 for Ni, 3 of 20 for Pb and 5 of 22 for Zn.

The small magnitude of change in soils estimated between surveys means that a significant change in concentrations at the GB scale was detected only for Cu. For this metal a small magnitude, but highly significant estimated increase in measure concentration of 2 mg/kg was detected. No other metal showed a significant change in measured concentration across GB. Stratification of the data by Broad Habitat, AVC and soil LOI revealed addition information about patterns of change in soil metal concentrations in different strata. All metals showed significant change for at least one category level. Importantly when considering stratification by so many categories, the potential for type 1 statistical error is increased in line which the number of strata considered. To include analysis by broad, AVC and soil LOI category involves separate statistical testing of approximately 20 separate categories for each metal. Since the significance of each is calculated separately and the cut off for statistical significance was 0.05, it will be expected that for each analyte, one type I error (i.e. a false positive where a truly non-significant result is deemed significant in a test) would be anticipated within the analysis. While multiple sample correct algorithms can be used to control for type I error arising from multiple testing for significance, in CS such algorithms are not used because the extra stringency for type 1 error come with the penalty of an increase probability of type 2 errors (i.e. a truly significant result deemed non-significant in a test). This could mean that truly significant effects at the national scale are missed with potential impact for the environment and policy. Where statistically significant effects are found careful review of relevant evidence that supports these as true responses is needed. In particular identification of potential drivers of change is needed as discussed briefly below.

Cadmium

Soil (0-15cm) Cd showed only relatively small changes between survey with an overall decline of 0.013 mg/kg (3%) in 2007 soils. The only statistically significant change found related to a significant decrease in soil Cd in Heath and Bog vegetation and Organo-mineral soils. The overall decline in Cd concentration might reflect declining deposition of this metal as detected in monitoring programs. Cd is a particularly labile metal and as a result it may be expect to show relatively rapid leaching from soils leading to reduced soil Cd levels. There is no obvious reason why either Heath and Bog vegetation or Organo-mineral soil should show significant reductions in soil Cd while other habitats do not. One possibility is that the remaining presence of Cd in some fertiliser may be maintaining Cd concentration in farmed soils, while in soils that are not subjected to fertiliser application during land management soil Cd loses may now exceed inputs allowing concentration to reduce.

Chromium

Soil (0-15cm) Cr showed a decrease of 0.9 mg/kg (4.6%) between 1998 and 2007. Broadleaved Wooodland, Arable and Horticulture and Improved and Neutral Grassland soils characterised by Crop and Weed and Fertile Grassland vegetation showed significant decreases in soil Cr levels. Decreases were also found in Mineral and Humus-mineral soils. Bogs and Organo-mineral soil showed significantly higher soil Cr concentrations. The results for Cr initially suggest that in managed habitats, particularly those where crops including grass for livestock are grown; the predominant trend of soil Cr concentration is down. This is not though the case with Acid Grassland, Dwarf Shrub Heath and Fen, Marsh and Swamp soils, which in addition to Bogs showed increased Cr concentrations. There are two potential explanations for the differences in trend in Cr concentration between habitats as observed.

The first potential cause of the apparent trend in soil Cr concentration is that measurement errors relating to difference in digestion efficiency between high pH, low LOI mineral soils and low pH, high LOI organic soils may be in part responsible. Comparisons of change across the 2007 soil pH and LOI range indicates that there is no trend for Cr concentration to show greater change in more organic rich soil (***Fig 7.2***). A slight trend for greater change in high pH soil is, however, indicated (***Fig. 7.1***). At a neutral pH, this effect results with a potential discrepancy of up to 2.7 mg/kg in back corrected 1998 concentrations. Effects of the method shift between surveys may, therefore, be the cause of some of the observed declines in mineral, neutral soils and associated habitats and vegetation classes. For low pH soils, effects associated with method change are likely to be less important as a cause of Cr concentration increase, since comparison suggests comparability between predicted 1998 and measured 2007 concentrations at higher pHs. In those habitats that are characterised by low pH, such as Bogs, Acid Grassland and Dwarf Shrub Heath, the increased Cr concentration found cannot, therefore, be disregarded as a methodological error, suggesting that in these areas deposition loads may still exceed loses.

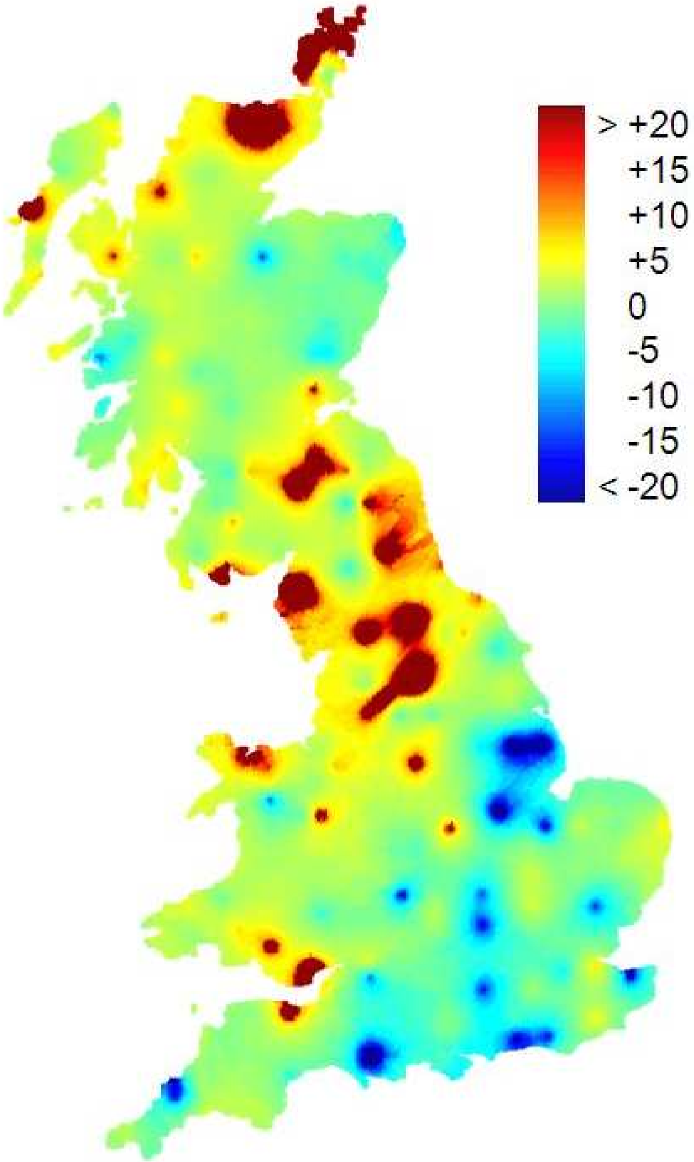
A second potential reason for the habitat difference found in the direction of change of soil Cr concentration that is also worth consideration is the role of cropping as an additional loss flux. The habitats where Cr concentrations were increasing, namely Arable and Horticulture and Grasslands, are predominately used for agricultural production. In these systems harvesting of plants and livestock may provide a route of loss of Cr from soil that is not relevant to areas not under agricultural production. Such increased loss may contribute to the reduction in soil Cr found in these areas when compared to uncropped areas.

Copper

Soil (0-15cm) Cu was the only metal that showed a significant change at the GB scale, increasing by a mean value of 2 mg/kg across the full dataset. Comparison of the effect of the change in digestion procedure between surveys by analysis of CRMs indicated that only a small change in measured Cu concentration resulted. This meant that only a small correction factor needed to be applied to the 1998 measured values. Analysis of change in soil Cu between back corrected 1998 and 2007 values in relation to both soil pH and LOI indicated that the magnitude of Cu change in soils could not be related to either parameter. The small size of overall change between CRM measurements made by different methods and also the absence of trends with soil pH and LOI suggests that the change in digestion procedure was not a major contributing factor behind the observed increase in soil Cu concentrations. Within habitats Improved Grasslands, Dwarf Shrub Heath and Bog also showed significant increases in soil Cu, as did the AVCs associated with these habitats. Significant changes in 3 of 4 soil LOI categories were also found.

Cu has a high affinity with soil organic matter and so it may be expected to show only very low rates of leaching loss from soils. Even if inputs of Cu in soils were reduced to zero, it would be anticipated that the Cu that has already been loaded into GB soils would take a considerable time (perhaps many centuries) to be completely leached. Monitoring networks have shown that the concentrations of Cu being deposited to soil are likely to be decreasing as a result of tighter emission controls. However in contrast to other metals, the magnitude of these decreases in deposition remains relatively modest. For example, Cu deposition had reduced by only 20% in a European wide survey of metal concentration in mosses compared to 72% for As, 72% for Pb, 60% for V and 52% for Cd. At the same time, while deposition has been slightly decreasing, there is a growing body of evidence to suggest that the use of Cu containing supplements in the livestock industry are potentially increasing the Cu load being added to soils under grazed areas and in areas to which animal manures are applied. Additionally Cu concentrations are known to be associated with sewage sludge material and green waste which are frequently recovered to land. The fact that among habitats, Improved Grasslands were found to contain Cu concentrations significantly increased by 2.6 mg/kg, suggests that the presence of Cu concentration in animal manure may indeed being playing a role in increasing national soil Cu levels to some extent. That Cu concentration were also increasing in all other habitats and significantly in some cases can be taken as quite strong evidence that currently Cu inputs still exceed outputs from leaching and cropping, leading to further elevation in Cu concentrations over time.

Figure 7.17: Map of estimated change in measures soil Cu concentration (mg/kg) in soils (0-15 cm) collected from across GB in CS in 1998 and 2007.



An analysis of the spatial structure within estimated change in soil Cu concentrations was conducted by using kriging to interpolate values for change (***Fig. 7.17***). This analysis was done using ordinary kriging to interpolate between the Countryside Survey sample points. Routine checking of data for outliers was conducted and the working data set was transformed using a normal score procedure to obtain a Gaussian distribution. The data were then interpolated on a 1km UK grid using ordinary kriging and finally, the kriged data were back-transformed to produce an interpolated map of % Cu change. Mapping highlighted significant spatial structure within the change dataset, with greatest increases being associated with hotspots in areas of the Northern England and Mid and South Wales uplands. Where decreases were indicated, these were associated most commonly with reductions in concentration in lowland areas of the South and East England that are associated with intensive arable land use. Mapping of change, thus, highlights that increases in soil Cu occurred principally in upland areas where both output fluxes associated with cropping may be limited and also where livestock rearing may play a role as a potential additional source of Cu input.

Nickel

Soil (0-15cm) Ni increased across all soils by 1.6 mg/kg between survey years. Two habitats showed significant decreases in measured soil Ni. These were Broadleaved Woodland and Arable and Horticulture. Crop and Weed vegetation also showed significant decrease. Ni increased significantly in Neutral Grassland and Bogs. As decreases were concentrated in habitats associated frequently with neutral low organic soils, this raises the possibility that differential digestion efficiency may be a factor in the observed difference, as was suggested to be the case for Cr. Comparison of trends of change between back corrected 1998 and 1998 measurements, however, suggests that this was not the case as no trend with either pH or LOI was observed (***Fig. 7.1 and 7.2***). The fact that the habitats that showed increases in Ni are associated with different soils types also suggests that analytical artefacts are not the primary cause of the observed change. A second potential cause of change may be the role of cropping as an additional loss flux for this metal as also highlighted for Cr. In particular in Arable and Horticulture area, harvesting of plants may provide an additional route of loss that allows soil Ni concentrations to decrease. Such losses would not be relevant to less productive land, such as Bogs, where removal of plant biomass does not regularly take place.

Lead

Soil (0-15cm) Pb concentrations showed a small non-significant decrease between surveys. This is potentially consistent with an overall loss of soil Pb, in particular as the move to unleaded petrol has substantial decreased Pb inputs over the past two decades. Although the overall dataset indicated slight losses, two habitats showed significant increases. There is no obvious reason why these two habitats, Improved Grassland and Dwarf Shrub Heath should show such increases, particularly as they are associated with different soil types. Among AVCs and soil type no significant change in soil Pb concentrations were found. The relatively small change in measured soil Pb and limited significant change in only a small number of unrelated habitat strata suggests that the high affinity of Pb to soil organic matter, which results in long predicted residence times for of Pb in soils, may currently be limiting rates of Pb loss from soils. Thus while deposition maybe decreasing, soil Pb concentrations may be doing so only very slowly or not at all.

Zinc

Zn (0-15cm) showed a small non-significant decrease between surveys and Zn concentrations were significantly reduced in two habitats, Arable and Horticulture and Neutral Grassland. No dependency of change between back corrected 1998 and 2007 measurements on either soil pH or LOI was detected in the dataset. This suggests that the decreases seen are probably not the result of an analytical artefact relating to different efficiencies of soil digestion. Instead the potential role of cropping as an additional loss flux as highlighted earlier for Cr and also for Ni may be important. As deposition rates decrease, in those areas where there is loss both from leaching and cropping it is possible that outputs may exceed current rates of metal inputs leading to a small, but in some cases significant, overall loss of soil Zn.

7.4.1 Policy implications

The results of the comparison of back corrected 1998 and CS in 2007 analyses indicated that, as would be expected, only relative small changes in soil trace metal concentrations had occurred between surveys. For one metal, Cu, the difference (an increase) was statistically significant. For all metals when data was stratified further, statistically significant differences were seen. For Cu these were mainly associated with significant increases, for two metals Cd and Pb, the changes were small and apparently idiosyncratic; while for three metals (Cr, Ni, Zn) the changes were somewhat similar with reduction seen particularly in crop lands and no change or in some case slight, and sometimes, significant, increases found in less managed habitats. Overall the results suggests that at present the changes in deposition that have occurred over recent decades have yet to lead to substantial changes in measured soil metal concentrations. For some metals, such as Cu and Cd it is likely that additional sources (animal manures and possibly sewage sludge, manures and compost for Cu and fertiliser for Cd) beyond atmospheric inputs are important in maintaining or even increase soil concentrations principally in managed areas. For the remaining metals, especially Cr, Ni and Zn, there is some suggestion that in areas where cropping takes place, output fluxes may now exceed inputs meaning that soil concentrations can start to decline. Overall, this suggests that the managed landscape where intensive cropping takes place, but sewage sludge, animal manures and composts are rarely applied may be among the first habitats to show a return of GB soil metal concentrations from their current slight-moderately elevated states to their pre-industrial background concentrations. These areas could, thus, be a focus for future monitoring.

7.5 References

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8. Soil invertebrates

Summary

- **There were an estimated 12.8 quadrillion ($1.28x10^{16}$) soil invertebrates present in the top 8 cm of Great Britain soils during the time of Countryside Survey sampling in 2007. Comparing these results with those from the survey in 1998 has enable change in soil biodiversity to be estimated at a national scale.**
- **A significant increase in total invertebrate catch in samples from soils (0-8cm) from all Broad Habitats, Aggregate Vegetation Classes and soil organic matter categories, except for agricultural areas on mineral soils, was found in Countryside Survey in 2007. The increase in invertebrate catch was mainly the result of an increase in the catch of mites in 2007 samples. This resulted in an increase in the mite: springtail ratio, but a decreased Shannon diversity due to the dominance of mites in 2007 cores.**
- **A small reduction in the number of soil invertebrate broad taxa (0-8cm) was recorded which is not inconsistent with reported declines in soil biodiversity. However, repeat sampling is required to ensure this is not linked to different seasonal conditions in the two sampling years. Further analysis through focussed study may be needed to assess whether the changes in soil chemistry, land management, annual weather patterns or merely natural population variation can explain observed soil invertebrate community changes.**

8.1 Policy background

Key Question: Does CS provide any evidence to indicate that there has been a loss of soil biodiversity as has been stated by the EU?

Measurements:
Enumeration of the number of soil invertebrate presence within Tullgren funnel extractions of 927 separate 4 cm diameter, 8 cm long soil cores collected from plots across GB to give: 1) total catch of invertebrates from all broad taxa; 2) the number of broad taxa represented by the presence of at least one individual in a core; 3) total catch of mites and springtails; 4) the ratio of Mites : Springtails; 5) the Shannon Diversity statistic calculated using counts of the number of individuals within broad taxa including springtail superfamily. From this analysis CS in 2007 has provided:

- **Whole Broad Habitats, Aggregate Vegetation Class and soil type stratified assessments of the characteristic (total catch, broad taxa representation, total catch and relative catch of mites and springtails, Shannon Diversity) of soil invertebrate communities across Great Britain.**
- **Information of the change in characteristic of soil invertebrate communities in Great Britain soils (0-8cm) since initial measurement in Countryside Survey in 1998.**
- **Data to contribute to analysis of changes in vegetation, selected soil properties and other habitat characteristics between successive Countryside Surveys in 1998 and 2007.**

The activities of the soil biota are critical for the provision of many important soil functions and resulting ecosystem services. These include, but are not limited to, biomass production; storing, filtering and transforming nutrients, contaminants and water; and acting as a biodiversity pool from which future novel applications and products can be derived. Because they are intimately involved in many important soil functions and are fundamental to maintaining soil quality, the biological components of soils have considerable potential as indicators of soil quality. National-level requirements for biological indicators were outlined in the Soil Action Plan for England (Defra, 2004), and have been investigated in a series of projects funded by Defra as part of the UK Soil Indicators Consortium. These have been assessing the relative performance of a range of potential soil bioindicators under field conditions.

At present comparatively little is known about the biodiversity of soil compared to, for example, above ground diversity. In the microbial realm, molecular approaches such as terminal restriction fragment length polymorphism (tRFLP), phylogenetic microarrays and metagenomics are starting to reveal patterns in the diversity and distribution of soil microbes. For the soil meio-, meso- and macro-fauna, molecular approaches to biodiversity assessment still remain in development. For some key groups, such as earthworms and springtails, good keys to the UK and other national fauna do exist, although, even in these cases, traditional morphological taxonomy can be hampered by cryptic speciation (i.e. occurrence of groups of species which are reproductively isolated from each other, but have high morphological similarity) and other taxonomic uncertainties. Beyond these better known groups, in taxa like mites and nematodes, there are significant issues for morphological identification associated with the lack of keys, laborious nature of the work and declining expert base.

Because they are often poorly known, few soil species are recognised for their conservation value. A few, such as some ants and fungi are covered by UK Biodiversity Action Plan (UK BAPs). However, as knowledge of soil biodiversity is often sparse, it is not well known if and how climate, land use, land management change and pollution affect populations of even these relatively well known and highly valued species, let alone the large amount of often hidden diversity that maybe present in soils. Beyond the few soil species covered by BAPs, there is a well recognised need to quantify soil biodiversity and determine whether it is possible to observe consistent patterns of population and community structure against a dynamic background of spatial and seasonal variability. Key questions in this area of research and conservation relate to determining if and how soil biodiversity changes over time, and the nature of the environmental drivers of any such changes. Large-scale biodiversity assessment, as well as long-term experiments and focussed mesocosm and laboratory studies are all important tools that can contribute data to improve current knowledge in this area.

8.2 Methods

8.2.1 *Proof of concept*

Invertebrate diversity was first measured as part of CS in 1998, and CS is the first and only national scale monitoring of soil biodiversity in the UK. The inclusion of invertebrate diversity measurements in CS in 1998 was partially driven by a 1996 report of the Royal Commission on Environmental Pollution (RCEP) on the Sustainable Use of Soils, which identified the development of indices of soil biological activity and diversity as a key research priority. In the RCEP report, it was recognised that a major difficulty in developing soil biodiversity based indicators was the requirement for baseline data on population and community structure and how these change over time. It was within this context of a need for baseline information, that an assessment of soil biodiversity was deemed timely within CS in 1998. CS was chosen as a suitable vehicle for the assessment because the existing survey infrastructure and sampling regime used in CS could provided a cost-effective framework for integrating a soil biological survey into a study that already included assessment for other land use, soil, vegetation and water parameters.

The aim of the soil invertebrate diversity measurements that were conducted in CS in 1998 (enumeration of mainly mesofauna groups collected by Tullgren extraction of a relatively small soil core) was not to sample and identify all invertebrate diversity within a given plot. Such an all-taxa biodiversity inventory would instead require use of a wide range of sampling techniques and would be a massive undertaking and highly expensive. Instead, the aim of CS in 1998 was to produce an initial baseline dataset of invertebrate group level community composition across all major soil groups and habitats of Great Britain. The strategy was to capture soil invertebrates that would be abundant and relatively cost-effective to identify. The group of soil invertebrates that best suited these criteria was the soil mesofauna. To sample the soil fauna, intact soil cores (4 cm diameter, 8 cm long) were collected for laboratory extraction of mesofauna. This approach was favoured over the use of an on-site hand-sorting technique which would be effective for macroinvertebrates or pitfall trapping which would preferentially sample soil surface active invertebrates. Identification of the extracted invertebrates was conducted to broad taxa (phylum, order) level for all available and successfully extracted samples (total 1076) collected from CS squares that were initially visited in the 1978 survey.

Table 8.1: Overview of soil invertebrate samples and level of taxonomic resolution for CS in 1998 and 2007.

	1998		2007	
	Main Plots	**km-squares**	**Main Plots**	**km-squares**
Total sampled	1286	256	927	238
Broad invertebrate taxa	1076	237	927	238
Mites (Acari)				
Separated to broad group [a]	-	-	238	90
Checked for Oribatid presence	963	237	238	90
Oribatids present	504	182	212	90
Oribatids identified to species [b]	504	182	-	-
Springtails (Collembola)				
Checked for Collembola presence/ Separated to broad group [c]	1076	237	927	238
Collembola present	837	233	816	238
Collembola identified to species	336	176	-	-

[a] Separated into Oribatids, Mesostigmatids and Prostigmatids.
[b] Presence/Absence data only.
[c] Separated into Entomobryoidea, Poduroidea, Neelidae and Sminthuridae.

While the invertebrate sampling undertaken in CS in 1998 identified and enumerated invertebrates extracted to broad taxa for all cores, it was also decided to undertake a limited identification of some taxa to a deeper taxonomic resolution (***Table 8.1***). Of the two main mesofaunal groups the mites and springtails, the mites (Acari) were checked for the presence of the most common major group, the oribatidae in the community sample; while the Collembola were identified into the superfamily groups of entomobryoidea, neelidae, poduroidea and sminthuridae. In the CS in 1998 samples, 504 samples were check for the presence of oribatids mites and all 1076 separated to superfamily for the Collembola. In all of the 504 samples checked for oribatids, additional identification of mites was undertaken to establish the presence/absence of individual oribatid species. This species level identification was conducted on a voluntary basis by Mr Frank Monson. For the springtails, species identification and enumeration was conducted for 336 samples representing approximately one third of available samples.

Analysis of the patterns of distribution of invertebrates in CS in 1998 detected significant differences in invertebrate diversity between Environmental Zones, Broad Habitats, ITE Land Classes, Aggregate Vegetation Classes and Soil Types. The 1998 CS dataset forms a valuable baseline that can be used to place specific site, region and country-scale changes within a regional and national environmental context. Resampling of the CS sites in 2007 provided an opportunity to determine whether these patterns of invertebrate diversity can be consistently detected against a background of spatial and temporal heterogeneity within soil communities.

The detailed protocols that were developed for soil invertebrate sampling in CS in 1998 have been used for the re-sampling in 2007. By returning to the majority of the CS plots first sampled in 1998, CS in 2007 can provide information on the temporal stability of soil communities. Resource limitations in 2007 meant that it was not possible to identify all invertebrates in all the cores that were collected from the remaining Main Plots that were first sampled in 1998. Of the cores that were available from re-sampled sites, a total of 927 cores have been enumerated to broad taxa. Of these 927 samples, superfamily level identification was conducted for the springtails for all cores and separation of mites to major group for 238. Limited resources meant that no species level identification could be supported, although all extracted invertebrates have been stored and can be made available for future identification on request. Soil invertebrate sampling and analysis throughout the CS project is summarised in ***Table 8.2*** below.

Table 8.2 Summary of rationale for measurement of soil invertebrate community composition in CS.

	Facts	Comments
History in CS	First measured in CS in 1998 for Main Plots in original 1978 squares only (total 1076 samples).	Repeat of most plots in CS in 2007 to initiate first ever national time-series for soil community assessment.
Country level reporting	No	CS in 1998 did not give country level statistics. Smaller data-set in 2007 limits power for Country level reporting for habitat, vegetation and soil types stratifications.
Links and compatibility to other monitoring programmes	No other GB wide survey or monitoring programmes for soil mesofauna. Earthworms surveys being undertaken in Scotland and as part of the Opal project run by the Natural History Museum, London.	CS unique in UK as soil biodiversity assessment is integrated with other survey approaches that measure land use, vegetation, soil properties and waters. Other countries such as the Netherlands, Germany and Canada also have programmes involving biodiversity assessments. Measurements of microarthropods are compatible with these schemes.
Uniqueness of CS	No other GB datasets	Only UK wide dataset for mesofauna communities. Only UK dataset with time series from repeat visits.
Value for money (Policy priority or interpretative value x cost)	Medium	Policy relevant and scientifically significant. Relatively low cost. Important to establish whether it is possible to detect meaningful changes against spatial and temporal variability. Important in interpreting other data, such as UK microbial survey and for integrated assessment.

Samples for invertebrate identification and enumeration were collected at all selected Main Plots. This included all of the original 1978 256 squares sampled in CS in 1978 that could be revisited. Sampling was undertaken using 4 cm diameter by 8 cm long white plastic core following the detailed field protocol described in Emmett *et al.* (2008) and briefly summarised in Chapter 1. Briefly, surface vegetation was removed to reveal the soil surface. Any litter layer present was not removed. The core was knocked into the ground to the full length of the core using a mallet and plate. In stony or shallow soils, the sampling point was moved if a full core depth would not be obtained. Any such variations in core location were recorded.

On removal of the core from the ground, the outside of the core was cleaned and any excess soil trimmed from the bottom of the core. Caps were then gently pushed over the ends of the core and the intact sample posted to CEH in Lancaster as the quickest route of return given the countrywide nature of the sampling programme. Soil invertebrates were extracted from cores as soon as possible using a dry Tullgren extraction method. This uses surface heating of the exposed surface of the core to drive the soil fauna downwards and out of the open bottom end of the core and into the collection bottles filled with a 70% ethanol preservative below. Once collected, soil invertebrates were identified to major taxa (Taxonomic level 1) and counted. The broad taxa categories used for enumeration was acari, araneae, chilopoda – geophilomorpha, chilopoda – lithobiomorpha, chilopoda, coleoptera, collembola – entomobryoidea, collembola – neelidae, collembola – poduroidea, collembola – sminthuridae, copepoda, diptera, diplura, diplopoda, gastropoda, hemiptera, hymenoptera, isopoda, lepidoptera, nematoda, nematomorpha, oligochaeta, opiliones, pauropoda, protura, pseudoscorpions, psocoptera, pulmonata, symphyla, thysanura, thysanoptera, unknown. All extracted invertebrates collected from counted cores have been stored in ethanol and are available for further species level identification to interested parties. Invertebrate numbers were reported for each quantified soil core.

8.2.2 Quality control

After an initial identification to broad taxa, mite group and springtail superfamily, at regular intervals the samples were reassembled and resorted, identified and enumerated by an alternative member of staff. This second identification and counting step was then compared with the original count to assess the potential for operator error during processing. If any substantive differences in count were found by this cross checking procedure, counting was halted and the differences in identifications that lay behind the discrepancies resolved by the counting team. Any such changes were noted on the record sheets kept for each sample.

8.2.3 Reporting

Change in the composition of the soil invertebrate communities as represented by counts of the macro and mesofaunal group collected by Tullgren extraction of soil cores collected in CS in 1998 and 2007 have been analysed using a mixed modelling approach using the SAS statistical software platform. The statistical approach used for analysing the data for change involved bootstrapping, which allows for non-normality in the data without the necessity to know details of the actual distribution. As such it provides a more accurate measurement of significance than alternative approaches. Annex F of Emmett *et al.* (2008) provides a background document describing the basis of the mixed model procedure. As well as looking for overall change at the GB wide scale, statistical analyses have been conducted to assess change of measured or calculated parameters soil community parameters within different strata within the data-set. These include analysis according to stratification by Broad Habitat, Aggregate Vegetation Class and Soil Loss on Ignition (LOI) category which are briefly described here:

- Broad Habitat - The Broad Habitat classification consists of 27 habitats which account for the entire land surface of Great Britain, and the surrounding sea. Countryside Survey reports on 10 major terrestrial habitats.
- Aggregate Vegetation Class (AVC) – is a high level grouping of vegetation types produced from a quantitative hierarchical classification of the different plant species found in the original Countryside Survey sample plots.
- Soil organic matter (LOI) category - mineral (0-8% LOI; 0-44 g C kg^{-1}), humus-mineral (8 – 30% LOI ; 44-165 g C kg^{-1}), organo-mineral (30 – 60% LOI; 165-330 g C kg^{-1}) and organic (60 – 100%; > 330 g C kg^{-1}).

Measured and calculated parameters that were used as inputs for the analysis were.

1. Total catch of invertebrates from all broad taxa to give a measure of overall abundance of invertebrates in CS cores.
2. Number of broad taxa represented by the presence of at least one individual in each CS core as a measure of community taxa richness.
3. Total catch of mites and springtails only since these two mesofauna groups usually comprised the majority of the invertebrates present in each core.
4. The ratio of Mites : Springtails, since this parameter was found to change in relation to climatic conditions as indicated by annual precipitation (highest mite: springtail ratio was found in plots where annual precipitation was highest within GB) in the 1998 data-set.
5. Shannon Diversity calculated for each sample using counts of individual number within broad taxa, including counts for springtail superfamily, as available for all 1998 and 2007 samples.

As well as analysis of each parameter according the outlined stratification, a spatial analysis was undertaken using geostatistics. For the measured parameters tested, namely total invertebrate catch, mite : springtail ratio and Shannon Diversity, the semi-variograms identified no spatial correlation at the regional scale. For this reason spatial interpolation or mapping of change is not feasible and as a result is not reported further in this chapter.

8.3 Results

8.3.1 Total invertebrate catch

The mean number of invertebrates collected from cores in CS in 1998 was 52.3 and 77 in 2007 (***Table 8.3***). This represented an overall increase of 47% in total catch in CS in 2007. The highest catches of invertebrates were in woodland habitats, with high catches also recorded in Acid Grassland and Dwarf Shrub Heath. Lowest numbers occurred in three habitats Arable and Horticulture, Improved Grassland and Neutral Grassland that are most frequently the subject of intensive management practices. Catches in Arable and Horticulture habitats in particular were notably low in both surveys.

Table 8.3: Changes in total invertebrate catch of soils (0-8cm depth) within a) Broad Habitats, b) Aggregate Vegetation Classes and c) Soil LOI categories across Great Britain. Arrows denote a significant change ($p<0.05$) in the direction shown.

a) Great Britain - Broad Habitats

	Total catch		Direction of significant changes
Broad Habitat	1998	2007	1998-2007
Broadleaved, Mixed and Yew Woodland	92.2	103.2	
Coniferous Woodland	90.4	152.4	↑
Arable and Horticulture	30.9	31.6	
Improved Grassland	38.5	57.5	↑
Neutral Grassland	42.2	86	↑
Acid Grassland	85.9	113.9	
Dwarf Shrub Heath	75.7	119.2	↑
Fen, Marsh and Swamp	64.1	84.3	
Bog	49.3	77.4	↑
All habitat types	52.3	77	↑

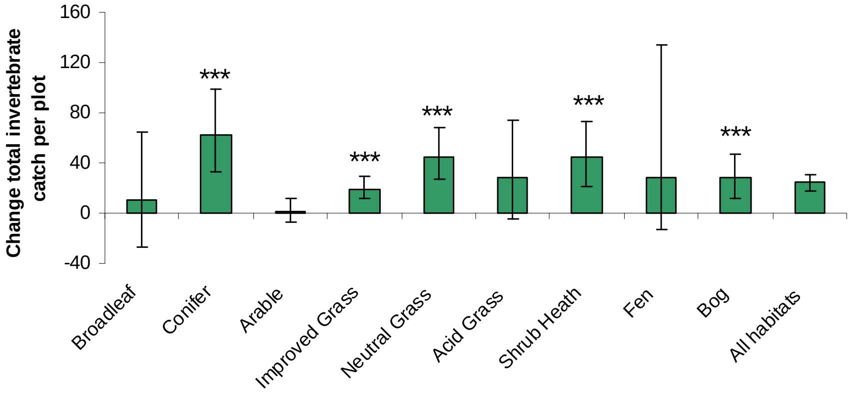
b) Great Britain - Aggregate Vegetation Class

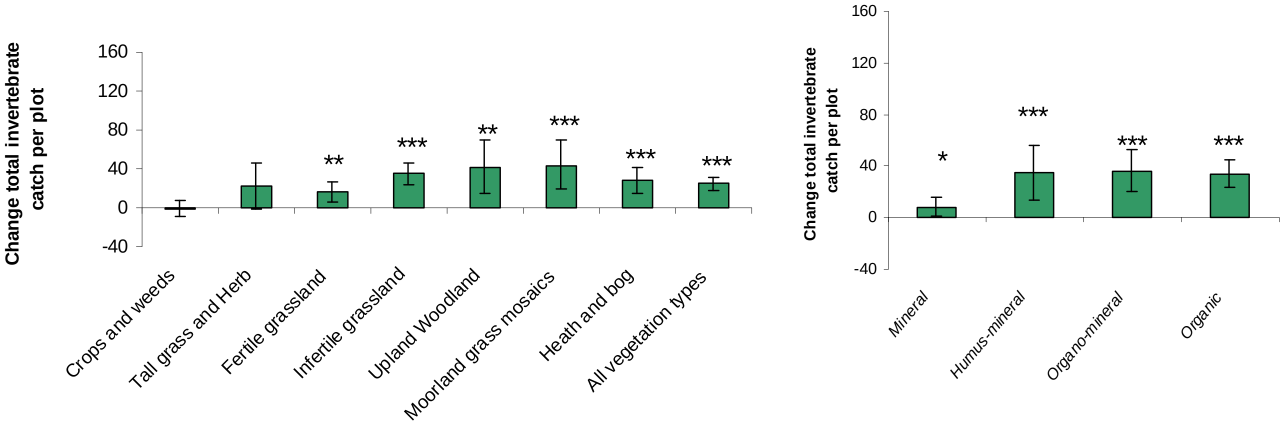
	Total catch		Direction of significant changes
AVC	1998	2007	1998-2007
Crops and weeds	31.6	30.2	
Tall grass and Herb	31.9	55.2	
Fertile grassland	36.2	52.5	↑
Infertile grassland	44.8	79.9	↑
Upland Woodland	97	140.4	↑
Moorland grass mosaics	84.3	127.6	↑
Heath and bog	60.6	89	↑
All vegetation types	52.3	77	↑

C) Great Britain - Soil LOI Category

	Total catch		Direction of significant changes
Soil LOI category	1998	2007	1998-2007
Mineral	36.7	45.1	↑
Humus-mineral	55.3	89.5	↑
Organo-mineral	81.6	117.9	↑
Organic	69.7	105.3	

Figure 8.1: Changes (+/- 95% CIs) in total invertebrate catch of soils (0-8cm depth) within a) Broad abitats, b) Aggregate Vegetation Classes and c) Soil LOI categories across Great Britain. Standard errors are indicated. Significant differences * p < 0.05, ** p < 0.01, *** p < 0.001 are shown.


a) Broad Habitats


b) Aggregate vegetation class

c) LOI categories

Analysis using the mixed model indicated that the increase seen in total catch in GB soils in CS in 2007 was highly significant (p<0.001). Stratification of the data to assess change by Broad Habitat indicated that a significant increase in catch was detected in 5 of 9 Broad Habitats ***(Fig. 8.1)***. For the remaining 4 habitats, small non-significant increases in catch were found. These were Broadleaved Woodlands, Acid Grassland and Fen, Marsh and Swamp which all showed non-significant increases of 12 %, 32.5% and 31.5% respectively; and Arable and Horticulture which showed only a 2% increase in mean catch. No habitat showed a mean decrease in total invertebrate catch.

The absence of a clear increase in total invertebrate catch, which was evident in all other habitats, and significant in most Arable and Horticulture areas, is particularly interesting because the absence of an effect is not the result of low sample numbers in the analysis. In fact Arable systems are the second best represented habitat, after Improved Grasslands in the repeat sampled soil invertebrate dataset with 217 enumerated samples. This suggests that the factor that is responsible for the general increase in invertebrate catches in soil cores sampled from across GB is not applicable to Arable and Horticulture systems.

Further stratification of the data by AVC indicated patterns of change that were generally in line with those indicated by the habitat analysis. No significant increase in catch was found between Crops and Weeds and Tall Grass and Herb, which are vegetation classes associated with arable landscapes, while total catch was significantly higher in all other vegetation classes.

Analysis by LOI class indicated significant change in total invertebrate catch in all classes, with three classes highly significant (p<0.001) and the mineral soil (LOI < 0-8%) significant at p<0.05. Smallest overall increase in total catch was found for the mineral soils in terms of both absolute numbers and percentage change. Since these included a large proportion of the Arable and Horticulture soils (189 of 371 soils in the 0-8% LOI category are from Arable and Horticulture habitats), this suggests that the low organic matter content of these soils, possibly in combination with arable land management practice may be a contributing factor preventing increase in the total catch of invertebrates in the mineral soil category to the same extent found in soil with higher LOI.

8.3.2 Total broad taxa in catch

The mean number of invertebrate taxa represented by at least one individual in soil cores in 1998 was 4.34 and was 3.85 in 2007 (***Table 8.4***). This represented an overall decrease of 11% in average taxa representation in CS in 2007 compared to 1998. This reduction is highly statistically significant (p<0.001). Because of the small size of the core sample used for invertebrate extraction in CS, the number of taxa that may be represented within a catch at any given plot is rather idiosyncratic. Further both the core size and extraction technique used (surface heating within a Tullgren funnel apparatus) is targeted at collecting mainly hard bodied soil mesofauna. Thus, while small arthropods such as mites and springtails are usually well sampled (Van Straalen and Rijninks, 1982), soft bodied meiofauna such as nematodes and tardigrade and larger macrofauna such as Oligochaetes, centipedes, millipedes and woodlice are not well represented in the extracted sample. As a result, within any one sample, the total number of taxa present can be affected not only by habitat and soil conditions, but also by the chance inclusion of individuals of larger invertebrates within the sample. Taxa representation as a result is subject to large variation in measurement between samples that is independent of fixed factor effects.

When analysed by Broad Habitats, the highest average number of invertebrate taxa was found in Broadleaved, Mixed and Yew Woodland in both the CS in 1998 and 2007 (***Table 8.4***). High taxa representation in these habitats is consistent with the high overall catches recorded in these areas, since there is a positive relationship between overall catch and number of represented taxa within the CS data-set. In remaining habitats, trends for representation of taxa in different systems varied slightly between surveys. Bogs showed low taxa richness in both surveys and Arable and Horticulture systems also had relatively low taxa richness that is consistent with the low overall catch in these areas in both surveys.

Table 8.4: Changes in total number of sampled taxa represented by at least one individual in soil samples (0-8cm depth) within a) Broad Habitats, b) Aggregate Vegetation Classes and c) Soil LOI categories across Great Britain. Arrows denote a significant change ($p<0.05$) in the direction shown.

a) Great Britain - Broad Habitats

	Number of broad taxa		Direction of significant changes
Broad Habitat	1998	2007	1998-2007
Broadleaved, Mixed and Yew Woodland	5.81	4.95	↓
Coniferous Woodland	4.35	4.66	
Arable and Horticulture	4.13	3.4	↓
Improved Grassland	4.54	3.74	↓
Neutral Grassland	4.53	4.33	
Acid Grassland	4.60	3.97	↓
Dwarf Shrub Heath	4.26	3.64	↓
Fen, Marsh and Swamp	3.94	4.11	
Bog	3.35	3.28	
All habitat types	4.34	3.85	↓

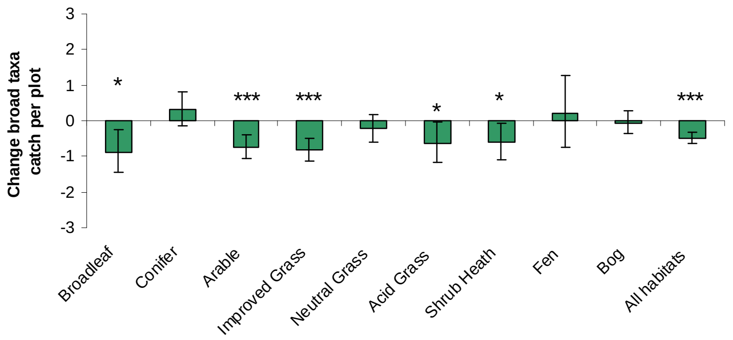
b) Great Britain - Aggregate Vegetation Class

	Number of broad taxa		Direction of significant changes
AVC	1998	2007	1998-2007
Crops and weeds	4.27	3.42	↓
Tall grass and Herb	4.16	4.15	
Fertile grassland	4.52	3.67	↓
Infertile grassland	4.62	4.23	↓
Lowland woodland	6.48	5.61	
Upland Woodland	5.00	4.61	
Moorland grass mosaics	4.34	3.97	
Heath and bog	3.56	3.36	
All vegetation types	4.34	3.85	↓

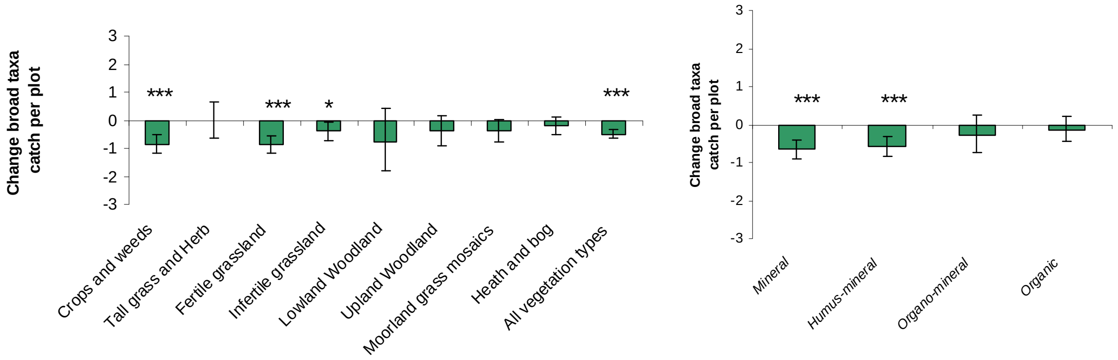
c) Great Britain - Soil LOI Category

	Number of broad taxa		Direction of significant changes
Soil LOI category	1998	2007	1998-2007
Mineral	4.37	3.73	↓
Humus-mineral	4.66	4.08	↓
Organo-mineral	4.51	4.25	
Organic	3.60	3.46	

Figure 8.2: Changes (+/- 95% CIs) in total number of sampled taxa represented by at least one individual in soils (0-8cm depth) within a) Broad Habitats, b) Aggregate Vegetation Classes and c) Soil LOI categories across Great Britain. Standard errors are indicated. Significant differences * p < 0.05, ** p < 0.01, *** p < 0.001 are shown.



a) Broad Habitats



b) Aggregate vegetation class

c) LOI categories

Analysis of taxa richness using the mixed model indicated that the reduction in the total number of collected taxa in CS in 2007 compared to 1998 was highly significant (p<0.001). Stratification of the data to assess change by Broad Habitat indicated that in 5 out of 9 cases (Broadleaved Woodland, Arable and Horticulture, Improved Grassland, Acid Grassland and Dwarf Shrub Heath), the reduction in taxa representation indicated was statistically significant ***(Fig. 8.2)***.

Analysis using AVC revealed further information about the changes in taxa representation between surveys. Thus, while all AVC categories showed a reduction in taxa richness, greatest change was found for Crops and Weeds and in Fertile Grassland. In both cases these changes were statistically significant (p<0.001), with a further significant decrease (p<0.05) also found in soils from Infertile Grassland. Because these Arable and Grassland areas are subject to the greatest anthropogenic influence through land management, this suggests that land management practice may be in some way influencing the representation and distribution of some soil taxa in these systems.

Analysis by LOI class indicated a reduction in taxa representation in all soil classes. The change in representation was greatest in the mineral (0-8% LOI) and humus-mineral (8-30% LOI) soils rather than in soils with a higher LOI. This is consistent with the reduction in taxa catch detected in the Arable habitats and Crop and weed AVC class and Improved Grassland habitat and Fertile Grassland AVC, since these habitats and vegetation types are extensively represented within the less organic rich soils within the low LOI class.

8.3.3 Total catch of mites and springtails

The average combined number of mites and springtails present in CS in 1998 was 38.9, compared to 72.1 in 2007. In 1998 mites and springtails comprised 74.3% of all invertebrates captured, while in 2007 this had increased to 93.6%. Springtails and mites, thus, increased in their overall dominance between the two surveys. Because springtails and mites dominate total invertebrates to such an extent, their patterns of abundance between habitats reflect those also found for total invertebrate catch (***Table 8.5***). The highest combined catches of mites and springtails were in woodland habitats (notably Coniferous Woodland), with high numbers also found in habitats such as Acid Grassland and Dwarf Shrub Heath. Lowest counts were found in Arable and Horticulture and Improved Grassland habitats. Since these habitats are often intensively managed, this suggests a potential influence of management regime on these two important soil mesofauna groups.

Table 8.5: Changes in combined catch of mites and springtails in soils (0-8cm depth) within a) Broad Habitats, b) Aggregate Vegetation Classes and c) Soil LOI categories across Great Britain. Arrows denote a significant change (p<0.05) in the direction shown.

a) Great Britain - Broad Habitats

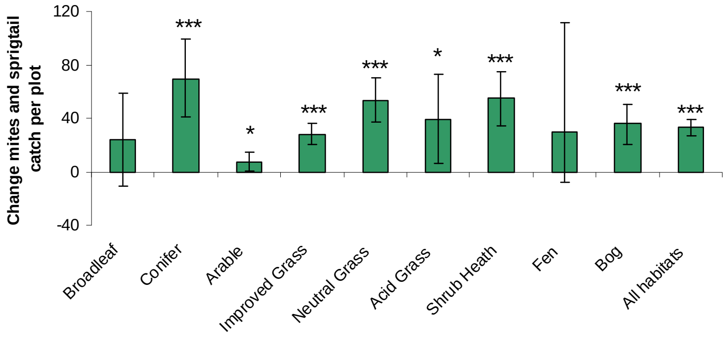
	Abundance mites and springtails		Direction of significant changes
Broad Habitat	1998	2007	1998-2007
Broadleaved, Mixed and Yew Woodland	68.8	93.7	
Coniferous Woodland	76.9	145.9	↑
Arable and Horticulture	21.0	28.1	↑
Improved Grassland	25.4	53.3	↑
Neutral Grassland	28.1	80.5	↑
Acid Grassland	69.4	108.5	↑
Dwarf Shrub Heath	61	115.8	↑
Fen, Marsh and Swamp	55.4	77.7	
Bog	38.1	74	↑
All habitat types	38.9	72.1	↑

b) Great Britain - Aggregate Vegetation Class

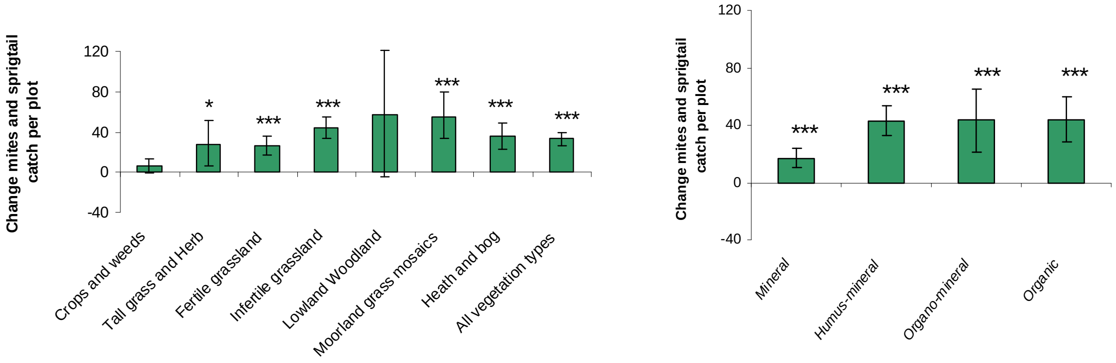
	Abundance mites and springtails		Direction of significant changes
AVC	1998	2007	1998-2007
Crops and weeds	20.9	26.6	
Tall grass and Herb	21.6	50.1	↑
Fertile grassland	22.2	48.3	↑
Infertile grassland	30.9	74.7	↑
Upland Woodland	85.7	133.8	
Moorland grass mosaics	66	122.2	↑
Heath and bog	49.2	85	↑
All vegetation types	38.9	72.1	↑

c) Great Britain - Soil LOI Category			
	Abundance mites and		Direction of significant
Soil LOI category	1998	2007	1998-2007
Mineral	24.4	41.1	↑
Humus-mineral	41.1	83.9	↑
Organo-mineral	68.5	112.9	↑
Organic	58.6	101.5	↑

Figure 8.3: Changes (+/- 95% CIs) in the combined catch of mites and springtails from soils (0-8cm depth) within a) Broad Habitats, b) Aggregate Vegetation Classes and c) Soil LOI categories across Great Britain. Standard errors are indicated. Significant differences * p < 0.05, ** p < 0.01, *** p < 0.001 are shown.



a) Broad Habitats



b) Aggregate vegetation class

c) LOI categories

Data analysis using the mixed model indicated that the increase in the combined catch of sprigtails and mites in CS in 2007 compared to 1998 was highly significant (p<0.001) when considering all soils ***(Fig. 8.3)***. Stratification of the data to assess change by Broad Habitat indicated effects that were consistent with those for total invertebrate number. Thus, combined mite and springtail catches were increased in all analysed habitat classes and no habitat showed a mean decrease in mite and springtail catch. For 7 out of 9 habitats (Coniferous Woodland, Arable and Horticulture, Improved Grassland, Neutral Grassland, Acid Grassland, Dwarf Shrub Heath and Bog) the increase in combined mite and springtail catch was statistically significant, with Arable and Horticulture soils showing the lowest overall change. Because of the low starting point in Arable soils, the actual percentage increase in combined catch (34.2% increase) was only slightly below the lower end of level of change found for the remaining habitats (36-186%). The remaining 2 habitats each showed non-significant increases in combined catch.

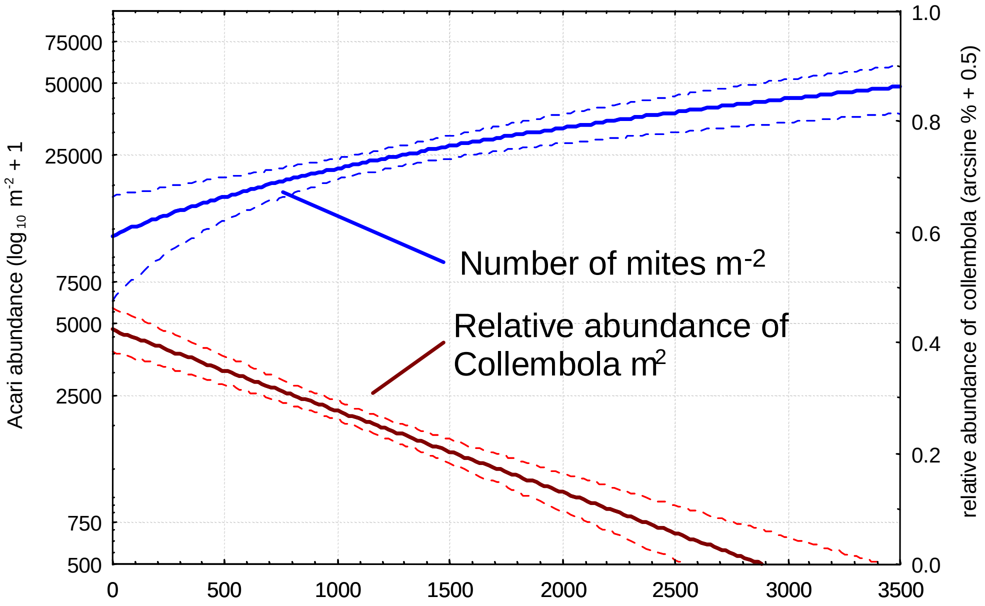
Analysis by AVC indicated an effect of vegetation on combined mite and springtail catch in line with those for total invertebrate numbers. A significant increase in the combined catch was found in all vegetation classes with the exception of Crop and Weeds and Coniferous Woodland. Analysis by LOI class indicated significant change in mite and springtail catch in all classes. Absolute size of the increase was lowest for the mineral soil (LOI < 0-8%), with the other soil classes each showing similar change. However, when, changes are calculated as percentage difference from CS in 1998, the change in the mineral soils (68%) is not inconsistent with the percentage change in the remaining LOI categories (65%-104%). That a significant increase in combined mite and springtail catch was found for the low LOI soil, suggests that the limited changes in total mite and springtail catch that were seen in Arable habitats dominated by the Crop and Weed AVC category is not merely a result of the low LOI of soils in these areas. Instead other land management practices may be important in limiting the extent of observed change.

8.3.4 Ratio of mites : springtails

Analysis was conducted of the change in the ratio of Mites : Springtails, since this parameter was found to vary in relation to annual precipitation (and as a result habitat) in CS in 1998. Highest catches of mites were found in plots at which rainfall was highest, while springtails favoured lower rainfall plots. Mite: springtail ratios, thus, varied systematically with increasing rainfall ***(Fig. 8.4).***

In CS in 1998, the average mite: springtail ratio in GB soils was 6.3 and in CS in 2007 this value had increased to 8.9 *(**Table 8.6, Fig. 8.5**).* Highest mite: springtail ratios were found in habitats that are associated with high rain fall particularly in upland regions of GB. A pattern that is consistent with the recognised trend ***(Fig. 8.4).*** Habitats with highest mite : springtail ratio were Bog, Dwarf Shrub Heath and Acid Grassland. Woodlands were intermediate, while values in Arable and Horticulture, Neutral Grassland and Improved Grassland soils were the lowest of the studied habitats. The pattern of mite: springtail ratio found between the Broad Habitats for in CS in 2007 supports the importance of moisture availability on the relative abundance of the major meiofaunal groups as indicated initially in CS in 1998.

Figure 8.4: Mite abundance and relative abundance of Collembola in relation to mean annual precipitation. Trends (with 95% confidence intervals) are calculated based on data collected from 1097 Tullgren samples collected across GB in 1998.



All Broad Habitats included in the stratified analysis showed a significant increase in mite: springtail ratio. Statistical analysis indicated that this increase was significant in all habitats except for Dwarf Shrub Heath and Bog; the two habitats that had the highest ratios in both CS in 1998 and 2007. The significant increase in the mite: springtail ratio found in the majority of habitats was largely the result of an increase in the total number of mites caught rather than a reduction in springtail catches. The increase in mite numbers is also the major reason for the increase in both the combined number of mites and springtails and total invertebrate catch (since mites are a major contributor to overall invertebrate numbers).

Analysis of the data by AVC indicated clear effects of vegetation class on mite: springtail ratio. These effects were largely consistent with the trends found for Broad Habitats. There was a significant increase in the mite: springtail ratio in all vegetation classes except Moorland Grass Mosaic and Heath and Bog, the two classes for which ratios in CS in 1998 and 2007 were highest.

Analysis by LOI class was also consistent with the changes in mite: springtail ratio across other stratifications. A significant increase in the mite : springtail ratio were found in mineral, humus-mineral and organo-mineral soils associated with the lowland habitats and vegetation classes in which mite: springtail ratio showed a significant increase. Only in organic soils associated with upland areas was the increase in ratio between the 1998 and 2007 not significant.

Table 8.6: Changes in ratio of mites : springtails in soils (0-8cm depth) within a) Broad Habitats, b) Aggregate Vegetation Classes and c) Soil LOI categories across Great Britain. Arrows denote a significant change ($p<0.05$) in the direction shown.

a) Great Britain - Broad Habitats

	Mites : springtails		Direction of significant changes
Broad Habitat	1998	2007	1998-2007
Broadleaved, Mixed and Yew Woodland	5.54	10.08	↑
Coniferous Woodland	6.44	14.64	↑
Arable and Horticulture	1.83	5.31	↑
Improved Grassland	4.02	8.20	↑
Neutral Grassland	4.06	9.66	↑
Acid Grassland	10.53	18.39	↑
Dwarf Shrub Heath	13.02	11.40	
Bog	13.83	15.26	
All habitat types	6.3	10.9	↑

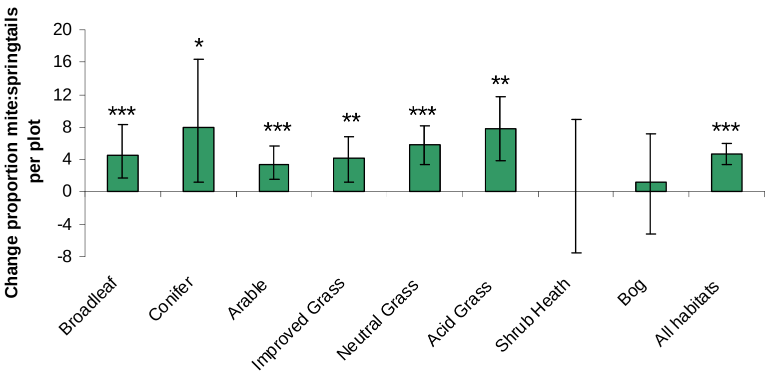
b) Great Britain - Aggregate Vegetation Class

	Mites : springtails		Direction of significant changes
AVC	1998	2007	1998-2007
Crops and weeds	1.87	5.3	↑
Tall grass and Herb	2.5	6.2	↑
Fertile grassland	2.62	7.91	↑
Infertile grassland	5.01	11.09	↑
Upland Woodland	6.7	11.29	↑
Moorland grass mosaics	13.91	17.48	
Heath and bog	14.77	17.54	
All vegetation types	6.28	10.87	↑

c) Great Britain - Soil LOI Category			
	Mites : springtails		Direction of significant
Soil LOI category	1998	2007	1998-2007
Mineral	3.57	7.50	↑
Humus-mineral	4.02	10.34	↑
Organo-mineral	9.27	15.40	↑
Organic	17.31	18.33	

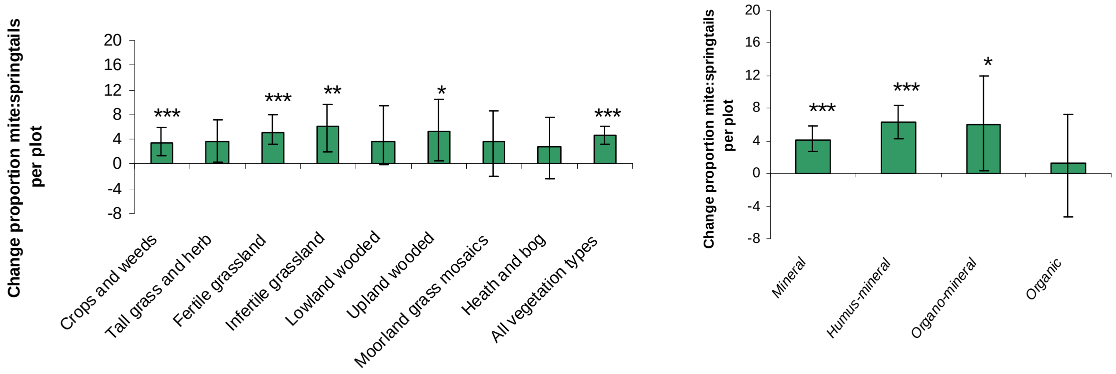
Figure 8.5: Changes (+/- 95% CIs) in the ratio of mites : springtails in soils (0-8cm depth) within a) Broad Habitats, b) Aggregate Vegetation Classes and c) Soil LOI categories across Great Britain. Standard errors are indicated. Significant differences * p < 0.05, ** p < 0.01, *** p < 0.001 are shown.

a) Broad Habitats



b) Aggregate vegetation class

c) LOI categories



8.3.5 Shannon Diversity

Shannon diversity was calculated using counts of the number of individuals within broad taxa (n.b. counts of springtails to superfamily were included as separate broad taxa in the analysis). Mean Shannon diversity in CS in 1998 was 1.02 and in 2007 this value has reduced to 0.72 (***Table 8.7***). This represented an overall reduction of 0.3 units in CS in 2007. Shannon diversity showed only a limited difference between different habitats. Broadleaved Woodland showed the highest Shannon statistic in both 1998 and 2007 (1.21 and 0.87 respectively); while Bogs showed lowest Shannon diversity in both surveys (0.71 and 0.52 respectively).

Statistical analysis indicated that the decrease in Shannon diversity in 2007 was highly significant (p<0.001) when considered for GB wide soils (***Table 8.7***). Stratification of the data to assess change by Broad Habitat indicated a significant decrease in diversity in 8 of 9 habitats (***Fig. 8.6***). Only in Fen, Marsh and Swamp was the reduction in Shannon diversity not significant.

Analysis by AVC indicated that the reduction in Shannon diversity was also significant in the majority of vegetation classes (***Fig. 8.6***). Of the 8 AVCs represented in the data-set, all showed a significant reduction in Shannon diversity except for Tall Grass and Herb. Analysis by LOI class indicated significant change in all soil LOI classes indicating that reduced Shannon diversity was associated with all soil types.

Table 8.7: Changes in invertebrate Shannon diversity based on enumeration to broad taxa of invertebrates collected from soils (0-8cm depth) within a) Broad Habitats, b) Aggregate Vegetation Classes and c) Soil LOI categories across Great Britain. Arrows denote a significant change (p<0.05) in the direction shown.

a) Great Britain - Broad Habitats

	Shannon Diversity		Direction of significant changes
Broad Habitat	1998	2007	1998-2007
Broadleaved, Mixed and Yew Woodland	1.21	0.87	↓
Coniferous Woodland	0.93	0.61	↓
Arable and Horticulture	1.10	0.85	↓
Improved Grassland	1.17	0.79	↓
Neutral Grassland	1.09	0.73	↓
Acid Grassland	0.89	0.55	↓
Dwarf Shrub Heath	0.87	0.63	↓
Fen, Marsh and Swamp	0.81	0.73	
Bog	0.71	0.52	↓
All habitat types	1.02	0.72	↓

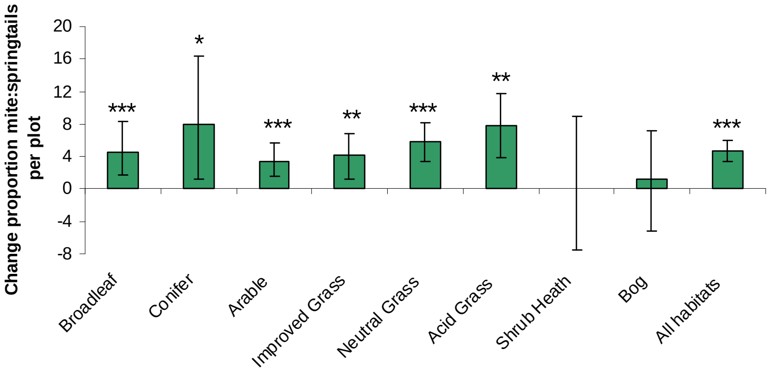
b) Great Britain - Aggregate Vegetation Class

	Shannon Diversity		Direction of significant changes
AVC	1998	2007	1998-2007
Crops and weeds	1.15	0.85	↓
Tall grass and Herb	1.09	0.92	
Fertile grassland	1.17	0.81	↓
Infertile grassland	1.11	0.73	↓
Lowland woodland	1.27	0.92	↓
Upland Woodland	1.04	0.67	↓
Moorland grass mosaics	0.85	0.57	↓
Heath and bog	0.74	0.54	↓
All vegetation types	1.02	0.72	↓

c) Great Britain - Soil LOI Category			
	Shannon Diversity		Direction of significant changes
Soil LOI category	1998	2007	1998-2007
Mineral	1.12	0.82	↓
Humus-mineral	1.12	0.74	↓
Organo-mineral	0.94	0.62	↓
Organic	0.69	0.51	↓

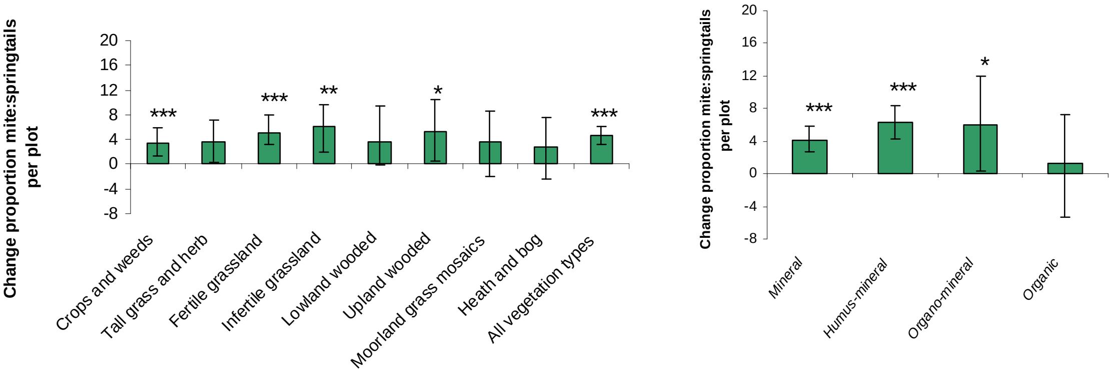
Figure 8.6: Changes (+/- 95% CIs) in invertebrate Shannon diversity based on enumeration to broad taxa of invertebrates collected from soils (0-8cm depth) within a) Broad Habitats, b) Aggregate Vegetation Classes and c) Soil LOI categories across Great Britain. Standard errors are indicated. Significant differences * p < 0.05, ** p < 0.01, *** p < 0.001 are shown.

a) Broad Habitats



b) Aggregate vegetation class

c) LOI categories



8.4 Discussion and Policy Implications

8.4.1 Introduction

Soils are critical components of the terrestrial ecosystems. They are vulnerable to the effects of anthropogenic activity, such as the release of pollutant chemicals and accelerating climate change. Within the soil the micro-, meio-, meso- and macro-fauna all play a critical role in the provision of many important soils functions and resulting ecosystem services. The poorly established taxonomy of many common soil macroinvertebrate taxa, coupled to a declining taxonomic base; means that the effects of human activity on subterranean invertebrate community structure is not well understood. These include not only nematodes, mites and springtails whose morphological taxonomy is “difficult”, but also groups such as Oligochaetes and Molluscs for which there is strong evidence for a high frequency of morphologically similar cryptic species (King *et al.*, 2008).

Countryside Survey represents one of only a limited number of programmes that have attempted national scale monitoring of soil biodiversity. CS is unique in co-ordinating soil biodiversity monitoring at a GB scale with other surveying approaches for land use, vegetation, soils and waters. Other countries such as the Netherlands, Germany and Canada do have programmes involving soil biodiversity assessments, however, unlike CS which is temporally synchronised in a single season, these other programs take a rolling approach to sample collection (i.e. sampling a certain percentage of sites in each year). As outlined, the aim of soil invertebrate sampling in CS was not to provide a comprehensive assessment of soil biodiversity, since this would require use of a wide range of techniques. Instead a snapshot of the abundance of principally the main soil mesofauna groups the mites and springtails, with some information on meiofauna (e.g. nematodes) and macrofauna, is gathered. Microbial diversity was not measured in the main part of CS, although bacterial diversity in all soils for which soil invertebrate communities were assessed have been analysed in separate work supported through NERC grants, raising the potential for a more integrated assessment of the microbial and invertebrate diversity data.

From the re-sampling in CS in 2007, the key policy question to be addressed was whether CS could provide any evidence to indicate that there has been a loss of soil biodiversity as has been stated in previous statements made by the EU? Because it was not feasible within available resources to identify collected fauna to species levels due to both the number of invertebrates captured and the challenge of species level identification for groups such as the oribatid mites, it is certainly not possible to provide a comprehensive answer to the policy question. Between year variation in seasonal weather patterns may also strongly influence patterns observed. While a complete answer is not possible, useful insight into the status of soil communities at the GB scale and with habitats, vegetation classes and different soil types can be derived from the survey results.

The re-sampling of soil communities in 2007 showed clear trends at the national scale. Mean number of invertebrates collected significantly increased across GB. Overall there was an increase of 47% in total catch in the CS in 2007 survey compared to 1998. Calculated at the level of individual per m^2 based on the 4 cm^2 diameter of the sample core used, the total catch measured equates to around 41,500 individual soil invertebrates per m^2 within the top 8 cm of the soil in 1998 and over 61,252 in 2007. Values for individual habitats varied from around 25,000 individuals per m^2 for both 1998 and 2007 in Arable and Horticulture habitats to around 73,000 in 1998 and 89,000 in 2007 for Broadleaved Woodlands. The estimate of total catch / m^2 for Bog soils of around 39,000 for 1998 and 61,000 for 2007 are above the range of 5000-10000 in a dry summer (2003) found previously in peatland and birchwood soils (Osler *et al.*, 2006). Studies at the same sites in a wetter summer (2004) did produce values of 14,000-100,000 mite / m^2 and 1,500-26,000 springtail / m^2 that are more comparable with estimates from CS in 2007. Values for deciduous woodland are close to the upper limit of the range of 15,000-90,000 for the total catch of mites and springtails found in control and disturbed woodland (Maraun *et al.*, 2003). This suggests that the method used for invertebrate sample collection in CS produced estimates of abundance that are largely compatible with results from published studies. Scaling up estimates of invertebrate numbers to a GB scale based on measured density and GB land area indicates that there were an estimated 12.8 quadrillion (1.28×10^{16}) soil invertebrates present in the top 8 cm of GB soils during the time of CS in 2007. This number is up 4.1 quadrillion (4.1×10^{15}) since CS in 1998 when “only” 8.7 quadrillion (8.72×10^{15}) invertebrates were estimated to be present.

Stratification of the data indicated that the increase in total invertebrate catch was detectable in all habitats except arable and managed grassland areas largely associated with mineral soils. Because total invertebrate catch was dominated by mites and springtails, the increase in the combined total catch of these two groups was broadly consistent with patterns found for total invertebrate catch. An increase in the mite: springtail ratio indicated that the increase in combined mite and springtail and total invertebrate catch was mainly the result of an increase in the number of mites retrieved. Shannon diversity was reduced in all soils. This was partly the result of an increase in the catch of mites, the increased dominance of which within the samples results in a corresponding reduction in the Shannon diversity statistic, although the reduction in diversity was not solely the result of an increase in the dominance of mites, as a reduction in the richness of broad taxa represented by at least one individual in each core was also found.

8.4.2 Cause of change in soil invertebrate communities between surveys

An important consideration when comparing results between repeat surveys is to ensure that the methods used for both sampling occasions are comparable. In certain cases, changes in instrumentation, in available facilities or of staff can result in shifts in methods that require careful thought before conclusions are drawn from results. Because large differences in invertebrate catch were seen between the 1998 and 2007 surveys, consideration was given as to whether there were methodological shifts in 2007 compared to 1998 that could have contributed to the observed differences. Five stages of the sampling and enumeration process were identified within which potential variations in procedure could occur. Methods used in both surveys were compared in relation to these five areas and the potential impact of any sampling and handling differences between surveys considered.

1. Preparation of the plot area for sampling. In the field survey in CS in 2007, core sampling locations were decided according to instructions set out the field sampling protocol (Emmett *et al.*, 2008). The approach was consistent with that used in 1998. For sampling the cores used for invertebrate enumeration, surveyors were instructed to leave the litter layer present on the soil surface intact. In CS in 1998 similar instructions were not given explicitly to the surveyors. Observation of the receipt of core from both surveys suggests that in reality this potential discrepancy is of minor importance. For example, for grassland sites, cores were almost always received with the turf layer still intact at the top of the core throughout both surveys. This suggests that sampling in the large number of grassland plots present within CS was conducted in an identical way. For plots where grass was not present, it is harder to tell if the litter layer has been similarly treated. If the tendency was for litter removal in CS in 1998, but not in 2007, this could play a part in the higher catches in 2007 since invertebrate densities are highest in the surface litter layer and this layer would be more prevalent in the cores taken in the later survey. If this was indeed the case though, it would be expected that catches would be increased by a greater amount in woodland than grassland plots, since it is know from the intact vegetation that grassland plots were similarly treated. Comparison of the relative change in the woodland and grassland habitats suggests that in fact changes in catches in the two habitats were broadly similar. This suggests that differences in the treatment of the litter layer during sampling are not likely to be the cause of the different in community parameters observed between surveys.

2. Soil core insertion and on site handling. Exactly the same cores were used for CS in 2007 as were used in 1998 (white 4 cm diameter, 8 cm long plastic cores). Cores were knocked into the ground using a mallet and plate on both occasions. Once the core had been inserted and removed it was necessary to cap the core to prevent desiccation affecting invertebrate survival during transit. Caps used in CS in 1998 were designed to fit into the inner rim of the core, while those used in CS in 2007 fitted over the out rim. The caps that were used in CS in 1998 were noted to slightly compress the core during insertion, while the same was not true of the caps in 2007. For invertebrates to escape from soils during Tullgren extraction, it is necessary that they are able to freely move through the soil profile to allow escape and capture. It is conceivable that the slight compaction of CS in 1998 soils may have impeded invertebrate escape during extraction with a resulting small reduction in catch in CS in 1998. While a compaction effect on Tullgren extraction can not be fully excluded, the extent of compaction of cores in 1998 was actually rather small. Given the magnitude of the shift in community parameters between surveys, it is difficult to envisage that this small difference could have lead to the almost 50% increase in catch found in 2007 compared to the earlier survey, particularly as catches in both surveys are towards the upper range of previous invertebrate counts taken in similar habitats (Osler *et al.*, 2006; Maraun *et al.*, 2003).

3. *Core transport to the laboratory*. During both the 1998 and 2007 surveys, the fauna cores were immediately placed into cool boxes after being dug from the soil and then posted first class to the laboratory at the first opportunity. Return by post was selected as the most rapid means of core return even from distant locations. It was acknowledged during initial survey design that the transport process was not well controlled and that the cores may be subject to stressful conditions, notably high temperatures, as sampling was mainly conducted over the summer months. Many soil invertebrates have a low tolerance to heat stress. Thus it is certainly possible that some temperature intolerant invertebrates in particular cores may have been lost (i.e. died) during transit. Because the same approach to core return was used and also because the post service worked equally effectively for both surveys, this suggests that differences in the time of transit, while possibly affecting the integrity of individual samples, can not account for community changes detected between surveys. Further work to trace temperature data relating to the survey period is needed to investigate if different in average conditions during transit were prevalent between survey that could play a role.

4. Soil invertebrate extraction method and conditions. Different methods of extraction will collect a different sample of invertebrates from a given sample. Tullgren extraction is particularly well suited to the collection of hard bodied mesofauna groups such as mites and springtails (Van Straalen and Rijninks, 1982). Exactly the same Tullgren funnel system was used for invertebrate extraction in both Countryside surveys. In CS in 2007, the funnel system was housed in a laboratory that received direct sun and so regularly reached temperature of 25^{o}C; while in CS in 1998, the extractions took place in a laboratory that was shaded and so ambient conditions did not regularly reach these higher temperatures. High temperatures can be expected to stress soil invertebrates resulting in possible mortality within cores meaning that individuals are not extracted. It was initially a concern in CS in 2007 that the high ambient temperatures in the laboratory used for the extractions could affect invertebrate catches, with high temperature resulting in some mortality within cores and so lower catches. Since actual catch observed in CS in 2007 were significantly higher than in 1998, it seems unlikely that ambient conditions had any effect on the efficiency of soil extraction and ultimately on observed community change.

5. Soil invertebrate sorting, identification and enumeration. Different personnel were involved in enumeration in the 1998 and 2007 surveys. This could lead to discrepancies between surveys. However, the involvement of multiple staff for sorting and identification in both surveys and also the use of quality assurance checks during enumeration are both factors that suggest that identification and counting errors are unlikely to lie behind observed community change found between survey years.

As outlined, a comparison of the detailed protocols for the two surveys indicated only small discrepancies between surveys. These related to tube capping, ambient conditions during extraction and changes in staff involved in enumeration. In practice the changes were actually rather small. The majority of the two procedures (cores, sampling method, return procedure, Tullgren system, quality assurance system) were rather similar. Given the magnitude of community changes, it seems unlikely that changes in capping, which results in slight core compaction, could account for the difference in catches seen. Ambient temperature during sampling would have been expect to lower catches in 2007 compared to 1998; while quality assurance and training procedure precluded difference resulting from personnel change. For this reason it is difficult to argue that the difference seen in soil invertebrate community between surveys; namely an increased catch of especially mites, leading to a high mite: springtail ratio and higher combined mite and springtail number coupled with a reduction in diversity resulting from both increased mite dominance and lower representation of broad taxa in CS in 2007 samples are solely down to methodological difference. Real differences in community parameters between sample years seem, instead, to be the most reasonable explanation.

8.4.3 *Initial attribution of soil invertebrate community change*

The lag in completing the enumeration of the soil fauna means that at present, attribution of changes in the soil invertebrate community remain in process. Even though detailed attribution of changes in soil invertebrate community structure is yet to be completed, it is possible even now to identify a number of potential candidate drivers that could be responsible for the quite substantial changes detected in soil communities between the two survey years.

Soil invertebrate communities are known to be sensitive to climatic condition. For example, in 1998 it was noted that the number of oribatid mites tended to increase in plots that are subjected to high mean annual rainfall, while springtail were more frequent in plots where precipitation was lower. The survey year of 2007 in the UK was one of the wettest summers on record. While it must also be recognised that 1998 was also a relatively wet summer, the rainfall amounts that occurred over the key survey month of June and July in GB in 2007 were notably higher and in some areas reached record levels indicating the extent of rainfall in the later survey year.

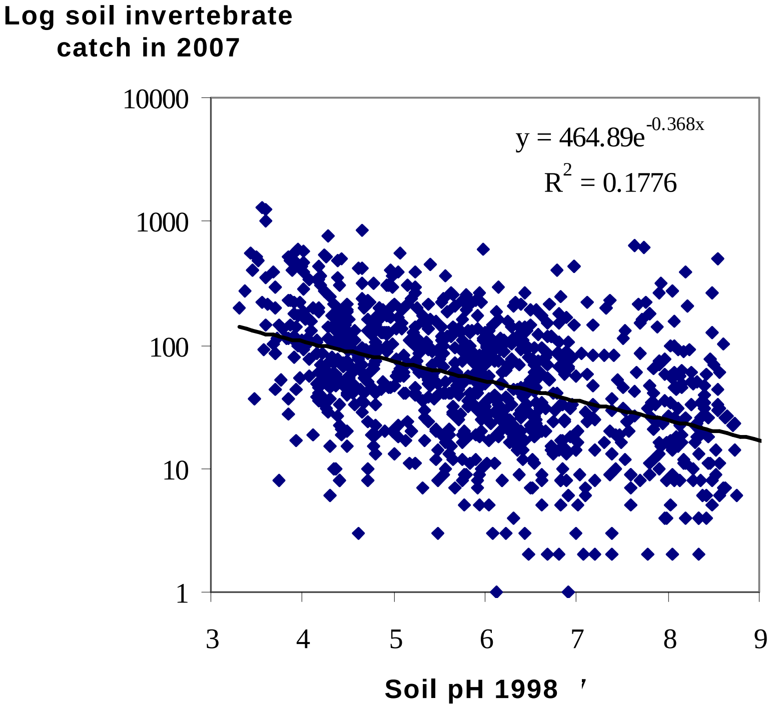
Wetter soil resulting from more rain can have both a positive and a negative effect on soil invertebrate catches from Tullgren extractions. Wet soils tend to swell. As a result this means that within the restricted volume of the sample soil core, a smaller weight of soil will be sampled. Lower soil layers in particular can, as a result, be missed. This reduced sampling at depth could result in the loss of some invertebrates from the sample. Since the majority of soil invertebrates live in or on the surface soil and soil litter layers, the actual number of individuals missed by the reduced sampling of deeper soils may actually be rather small.

A potentially more important effect of wetter soils may be that they maintain soil invertebrates in an active state that would not be the case in soils that were drier. It is well known that many soil invertebrates are sensitive to drought conditions. This is because most below-ground invertebrates have water permeable integuments and so are unable to resist water loss in drying environments. The sensitivity of some soil taxa to drought stress is recognised as an important determinant of their habitat preferences. As a result, the ecophysiology of desiccation tolerance and water balance in some taxa has been studied in detail. Some species such as earthworms and springtails, may burrow into the deeper soil layers where soil moisture is retained to escape from drought condition. Other species use a range of desiccation tolerance mechanisms (e.g. anhydrobiosis, estivation). If escape to moist deeper soil microsites is used, then this can prevent the initial capture of individuals within a defined depth soil sample. If a desiccation tolerance strategy is used, this can preclude the individual from responding to desiccation as a result of Tullgren extraction in a manner that allows capture. In either case this may limit invertebrate catches in drier soils. Initial attribution work focussing on 1998 and 2007 soil moisture measurements has indicated that there is no clear evidence for an increase in soil moisture content and sampling time (data not shown). This comparison does not preclude a potential influence of high rainfall on community parameters, since communities are likely to response to longer term changes in soil moisture regime. This means that even though there is no clear evidence of soil moisture levels between surveys, it remains possible that the high rainfall found in 2007 may indeed play some role in the observed different between soil communities found between survey years.

It is widely recognised that soil invertebrate communities are sensitive to a range of land management practices (Schon *et al.*, 2008), including land cover change (Black *et al.*, 2003), tillage regime and disturbance (Maraun *et al.*, 2003), pesticides and heavy metals (Frampton, 1999; Pedersen *et al.*, 1999) and nitrogen inputs (Lindberg and Persson, 2004). Because the changes in soil community structure detected between surveys was relevant to all habitats and vegetation classes, except intensively managed land mainly on mineral soils, attribution of changes in soil community composition to a particular driver must be relevant for a range of habitats and soil types. This means that changes in land management, such as stocking density, pesticide application rates or tillage regimes that apply only to certain habitat types, cannot explain all of the observed difference. At a national scale, one major difference that has occurred that has had a major effect on soil properties is the change in sulphur deposition and resulting effect on soil pH. Measures to reduce sulphur emission have resulted in reduced rate of deposition and a resulting increase in soil pH across GB of almost 0.5 pH units since 1978. The pH of the soil is known to play a key role in determining the structure of below ground communities. Within CS in 2007 a negative relationship exists between soil pH and total invertebrate catch ***(Fig. 8.7)***. This is explained because the highly abundant oribatid mite group do not favour neutral soil habitats associated with mineral soils in agricultural landscapes, but instead favour low pH organic soils in more upland areas. Thus, while important for determining overall composition of the soil community (e.g. high catch and dominance of mites in Dwarf Shrub Heath and Bogs), change in soil pH alone is unlikely to be a major driver of community change between survey years.

Comparison of communities in different habitats indicates that larger soil invertebrate communities are found in habitats such as woodland, while Arable and Horticulture and managed grassland have smaller communities with fewer broad taxa. It is often assumed because they are recently planted that Coniferous Woodland have a lower conservation value than older Broadleaved Woodland. Full species identification and enumerations of different woodland of known age would be needed to test this hypothesis for soil fauna. The GB wide survey from CS does indicate that in terms of community size and frequency of broad taxa, the two woodland types differ little in their harboured soil communities. For the conservation of soil biodiversity, on the basis of this analysis, woodlands emerge as potentially important targets. The small community size and low taxa representation for managed habitats, suggests impacts of land management practices such as tillage, fertiliser inputs and pesticide application on soil communities in these areas. Arable and grassland areas emerge as potential targets for soil biodiversity restoration.

Figure 8.7: Relationship between soil pH measured in soils sample (0-15 cm depth) in CS in 2007 and the total catch of soil invertebrates from soil core (0-8) depth



Within the land use and habitat survey of CS, one of the most notable changes over time has been a significant increase in woodland cover in the UK. Because woodland harbours large soil communities, it would be expected that this increase in woodland area would be beneficial to the national stock of soil invertebrates. Within CS, the designation of Broad Habitats is done by surveyors on each sampling occasion. This means that areas designated as woodland in each survey are done on the basis of current habitat distribution. Similarly vegetation class is determined directly by analysis of the flora present at the actual sample plots. Since the statistical analysis links invertebrate catch directly to recorded Broad Habitat and AVC in each category, changes in soil community composition between surveys cannot be linked simply to changing in woodland frequency. In fact, because new woodland may be expected to still be undergoing community succession, land cover change to woodland may be expected to have a slight negative effect on invertebrate community catch and diversity within woodland categories in a substantial amount of new woodland becomes included within later surveys. Increasing woodland may, therefore, play only a limited role as a driver of overall change.

8.4.4 Concluding remarks

Re-sampling of the soil invertebrate community was undertaken in CS in 2007 as part of the soil work-package according the published CS methodology. A total of 945 samples were enumerated. Results indicated an overall significant increase in total invertebrate catch in samples from all habitats, AVCs and soil types except for agricultural areas located predominately on mineral soils. The increase in invertebrate catch predominantly related to an increase in the catch of mites in CS in 2007 samples. This was shown in the increase in mite: springtail ratio found across GB and in many Broad Habitats, AVCs and soil LOI categories. The increased dominance of mites was a major factor that decreased Shannon diversity in CS in 2007 cores, although there was also a small reduction in the number of broad taxa represented in sample cores at the GB scale and also when the data was stratified to Broad Habitat, AVC and soil type (by LOI). A single repeat sampling campaign such as CS cannot prove or disprove whether a large scale and long term change in soil biodiversity is underway. Particularly effects of short term temporal effects, such as seasonal weather patterns, on invertebrate communities or sampling efficiency, cannot be excluded. Nonetheless, on the basis of the survey data it is certainly not possible to confidently refute the possibility that such a change may be occurring. This suggests that further analysis through focussed study may be needed to tease out whether the changes in soil chemistry, land management or climate are playing a role in the observed soil invertebrate community change.

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The Countryside Survey partnership has endeavoured to ensure that the results presented in this report are quality assured and accurate. Data has been collected to estimate the stock, change, extent and/or quality of the reported parameters. However, the complex nature of the experimental design means that results can not necessarily be extrapolated and/or interpolated beyond their intended use without reference to the original data.

For further information on Countryside Survey see www.countrysidesurvey.org.uk

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