Developing methods to detect change in the soil resource of a country with a Northern, Temperate Boreal Climate (Scotland).

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Abstract
Many nations and regions are currently developing soil monitoring schemes to assess the status of their soil resource. In Scotland, we have used an existing national scale, objective soil sampling scheme to assess different methods of sampling soils for the purposes of monitoring change, to assess new soil indicators (including indicators of physical soil quality) and to develop novel, rapid methods to assess changes in the soil resource. Early results have shown the value of archived soil material in detecting change over a prolonged (up to 30 years) period of time and indicate that the ability to detect change is influenced by sampling method and analytical methods.

Key Words
Monitoring, soil indicators, carbon, sampling

Introduction
Soils are under threat from economic, social and biophysical drivers. Soil monitoring schemes are being designed to determine the magnitude and direction of any change in order to more effectively manage the soil resource. However, detection of change is not straight forward. In Scotland, we are using an existing national scale sampling scheme to test three soil monitoring sampling systems currently in use in the UK. In particular we aim to determine their scientific and technical suitability, logistics and ability to detect change out-with normal variation in soil properties. Further, the re-sampling scheme will be used to determine suitable soil indicators for soils developed under a northern, temperate, Boreal climate.

Methods
From 1978-1988, the soil profile at 721 sites on a 10km grid (Figure 1) were described, sampled and analysed for a wide range of soil properties. This National Soil Inventory of Scotland (NSIS) provided an objective sampling scheme of a wide range of Scottish soil types and habitats. Re-sampling the NSIS is ideal for testing methods to determine changes in soil properties over time. In particular we aim to:

1. determine evidence of change in C content and macronutrients
2. compare sampling methods such as:
    - fixed depth sampling vs traditional sampling by soil horizon (pedological)
    - point sampling vs composite sampling over an defined area
3. measure new soil attributes to test their suitability as indicators of soil quality
4. develop and test new methods for assessing soil quality
5. assess the value of archival material in the detection and interpretation of change

In order to maintain this objectivity, we decided on a sampling scheme that allowed us to resample 25% of the original inventory over a 3 year period and was based on a 20km grid pattern aligned to the British Ordnance Survey grid (Figure 2). However, using a 20km grid meant that there were four possible sampling grids. In order to test if any of these would bias the results, specific soil and environmental attributes such as carbon content (Figure 3), base status and slope were examined for each of the four potential grids using data from the existing 10km NSIS dataset. Statistical analyses verified that there was no significant bias inherent in any of these grids. The final grid selected for the 2007-2009 re-sampling (NSIS2) had sampling locations at 20km intervals from the Ordnance Survey false origin used in UK topographic maps and has sample locations on the main outlying islands (Figure 2).

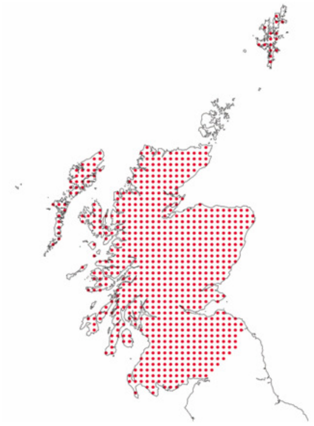

Figure 1. Original NSIS1 10km grid design.

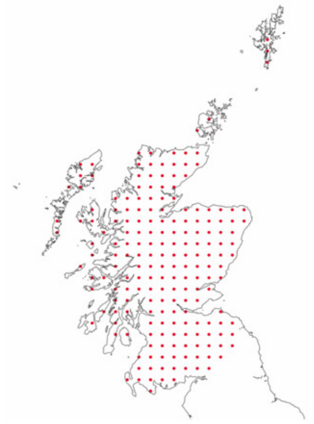

Figure 2. 2007–2009 NSIS2 20 km grid sampling sampling design.

Prior to implementing the sampling programme, strict protocols were written and field- tested to ensure compatibility between each of the lead surveyors. All samples were taken in spring to reduce the inter-annual variation in soil biological properties and each sampling team began by sampling the lowland sites and gradually moving to the more upland sites so that as many soils were sampled before the onset of the growing season as possible. Navigation to the site was undertaken by experienced soil surveyors using both new and original air photography to relocate the original sampling sites. Certain site characteristics such as slope, aspect and soil type had to match the original records (within acceptable error limits) before the site was deemed to be correctly located.

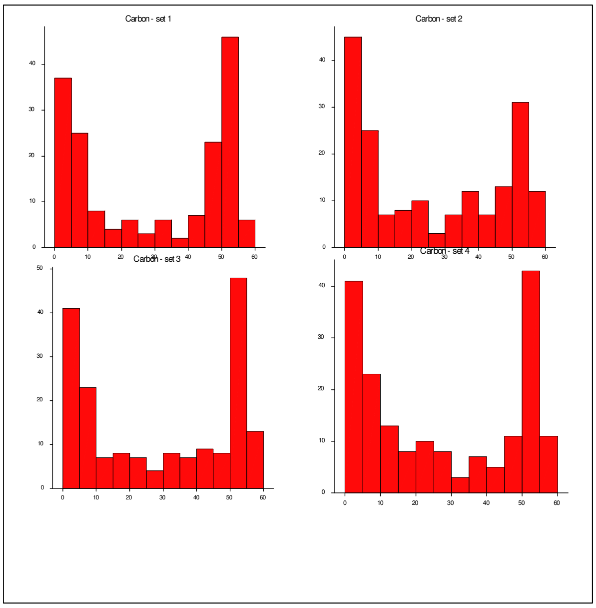

Figure 3. Frequency Distribution of topsoil carbon contents for each of the 4 possible 20km grids sampling schemes.

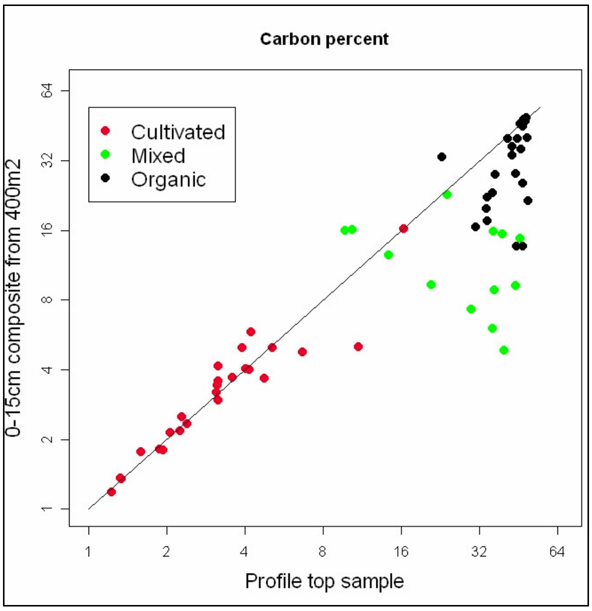

Figure 4. %C in cultivated, mixed organo-mineral and organic soils as determined from 0-15cm composite samples (y axis) and from profile bulk top horizon sample.

At each site, three main sampling methods currently in use in the UK were tested:

- Pedological horizon-based sampling
- Single, central 0-15cm core
- Composite auger samples 0-15cm

A soil profile was excavated to between 80 and 100cm and each of the main horizons were sampled by taking a bulk, disturbed sample from approximately a 10cm band around the mid point of each of these horizons. A single, centrally positioned vertical core was taken from the surface to a depth of 15cm and a composite 0-15cm auger sample was taken at 3-5m interval within a 20m grid centred on the main pit.

Triplicate samples to determine bulk density were taken from all soils and horizons. Cores to determine moisture retention and clods to determine aggregate stability were taken from mineral soils only. At each site there was also a sample design to assess short range variability in soil properties in order to help determine if detected changes are real or simply due to the inherent variation in soils. This comprised a further 4 smaller profile pits at varying, randomly set distances (up to 16m) from the main pit and aligned to the four cardinal compass points. Here, bulk density and bulk samples were taken from the uppermost, main horizon.

Results

Table 1 shows the number of samples collected over the three year field campaign and the attributes to be measured and evaluated. The soil samples are being analysed for the same range of properties that were determined in the original sampling scheme (%C, pH, micro and macronutrients, %N and particle size, base saturation) in order to determine if change has occurred and if this is within the local site variation. This latter component is vital to ensure that false results are not reported.

As well as analysing the recent samples, the archived soil material from the original sample scheme has also been re-analysed in order to minimise the effects of changes in analytical techniques and machines. This is a key component in the detection of change as early results appeared to indicate that carbon values were declining in Scottish soils, however, re-analysis of the archival material alongside the recent soil samples, showed that this change was not significant.

A number of soil indicators not currently in use in the UK are being assessed including Least Limiting Water Range (LLWR), aggregate stability and more novel, rapid methods of assessing various soil properties through the use of XRD and NIR techniques. These methods are quick to implement and, if suitable and robust regression equations can be developed between these attributes and attributes that are more costly and time consuming to measure, they may be useful as surrogate indicators that can be applied quickly and cheaply to a large number of samples.

There is also a major programme to develop methods to assess biological indicators and we are currently undertaking DNA analyses of the recent soil samples. Extracted DNA is also being archived at -80°C, providing a resource that can be utilised in the future, for example, as new assays are developed or as new questions are raised.

Our initial comparisons of the three sampling techniques have indicated that, for organo-mineral soils with thin (<15cm) organic layers overlying mineral horizons, composite auger sampling at 0-15cm produces results with too great a range to be of value in soil monitoring although this method may be suited to monitoring in homogenised cultivated horizons (Figure 4). Its applicability to monitoring in organic soils with >15 cm of organic material is still questionable due to the lack of information of overall thickness of the organic material.

Conclusion

Field sampling on a 20km grid has resulted in over 1400 disturbed, bulk soil samples from a wide range of Scottish mineral and organic soils that have been collected using strict protocols. Preliminary analyses have shown that archived soil material is invaluable to substantiate any apparent changes in soil properties over time. It is also becoming apparent that some sampling methods are not suitable for all soils. In Scotland, we are taking a rigorous approach to the analyses and the interpretation of results that inevitably extends the period between sampling and result reporting. However, despite the pressure from policy makers in governmental organisations and other stakeholders, it is vital that the results are robust and defensible.

Table 1 – Sampling of NSIS2: Indicators in **bold** are those suggested by UK-Soil Indicators Consortium as useful indicators of soil quality in UK.

Method/sample	**Number of samples**	**Analyses undertaken**	**What this will tell us?**
Pedological horizon-based sampling	701	LOI, **pH**, **%C**, **%N**, particle size, **macro** and **micronutrients**	a) Assessing changes in soil C content and stock. b) Assessing the effect of restrictions of sulphur emissions on soil pH or base status.
		XRD, FTIR, alkanes	c) High resolution functional analysis – new and cheaper methods to measure indicators. d) Assessing accuracy of site relocation. e) Have organic fractions/land use changed?
Bulk density	2087	**Bulk Density**	f) Determining carbon stocks and volume of available nutrients. g) Assessing soil compaction
Moisture release	198 (mineral soils only)	Least limiting water range (LLWR)	h) Determining the ability of soil to supply water for plants
Aggregate stability	132 (mineral soils only)	Aggregate stability	i) Determining susceptibility to erosion
Topsoil variability	725	LOI, **pH**, **%C**, **%N**; **bulk density**	j) Are detected changes in these properties within site variability?
Single central 0-15cm core	183	LOI, **%C**, **%N**, **pH, bulk Density**	k) Comparison of sampling methods - single core vs Horizon-based sampling or composite sampling
Composite auger samples 0-15cm	183	LOI, **pH**, **%C**, **%N**	l) Comparison of sampling methods - composite sampling vs Horizon-based sampling or single core
Soil/air interface core 0-5cm	183	**pH %C**, **%N** and **Metals**	m) Atmospheric pollutant concentration in near surface sample