Final Report **Project LQ09**

National Soil Monitoring Network: Review and Assessment Study

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EXECUTIVE SUMMARY

LQ09: National Soil Monitoring Network: Review and Assessment study (December 2006)

Project funders/partners: SNIFFER, Environment Agency, Defra, Scottish Environment Protection Agency, Scottish Natural Heritage, Scottish Executive

Background and objectives to research

The ultimate aims of the UK-Soil Indicator Consortium (UK-SIC) are to identify indicators of soil quality for soil monitoring and to develop a UK monitoring scheme that:

- better establishes the state of UK soils
- can be tailored to available resources and individual organisational needs
- will be designed to pick up statistically significant changes in soil quality
- builds upon previously funded research on the design of monitoring schemes.

SNIFFER Project LQ09 sits mid-way between these two stages with the objective of informing the development of a subsequent project whose purpose will be to design a UK soil monitoring scheme. The primary objectives of Project LQ09 were to carry out a stocktaking exercise of all environmental monitoring schemes currently in place (UK and EU) which might be useful in the context of soil monitoring and to assess whether these existing monitoring schemes could fit into a UK network for soil monitoring, highlighting data and spatial gaps and recommending improvements that could be made.

The main activities of LQ09 were to construct a catalogue of existing schemes and to code these against standardised criteria reflecting the scheme's potential value for a soil monitoring scheme able to report at a UK and devolved administration level. Of particular interest was whether schemes included indicators of soil quality currently being considered by the UK-Soil Indicator Consortium (UK-SIC indicators). An analysis of the strengths and weaknesses of each scheme was undertaken and generic weaknesses / gaps were iidentified. The potential for adaptating and/or combining current schemes to deliver a UK soil monitoring scheme was also investigated.

Key findings and recommendations

1. A total of 29 schemes were considered of relevance to these objectives and were included in the catalogue. Scheme entries were analysed using a coding scheme to provide an overview of current scheme attributes and to identify possible opportunities to integrate or adapt schemes to deliver a UK soil monitoring scheme. Attributes considered were; soil parameters, analytes and functions covered; ability to report and assess trends; statistical design; coverage spatially, vertically and temporally; data quality; availability of reports, data and samples and integration issues.

2. Key findings were: (i) Current schemes could be divided into three broad categories: spatial surveys (e.g. Countryside Survey (CS) and the National Soil Inventories (NSIs)), networks (e.g. Environmental Change Network (ECN), Level II Intensive Monitoring of Forest Ecosystems (Level II)) and long term experimental or monitoring sites (e.g. the Rothamsted experiment). (ii) Only four schemes included urban areas. (iii) The majority of schemes started in the 1990s and for this reason, very few spatial surveys (except the NSIs, CS and the Representative Soil Sampling Scheme (RSSS)) have a repeat cycle of measurements. (iv) All schemes hold data in

digital form and most have free or licensed access (with or without a fee) (v) All schemes have data available on one or more of the 15 UK-SIC indicators currently being considered for a minimum dataset while most GB or country-scale schemes have data available for 9 or more of the minimum dataset (vi) Major gaps in current schemes were identified as; relatively few or no data for three UK-SIC indicators currently being considered for a minimum datset; a lack of consistency in type and depth of sample taken and sampling procedure; a lack of consistency in methods of analysis; and a limited number of soil physical measurements. (vii) Some schemes, whilst having a statistical design appropriate for their purpose, do not have a design appropriate for a national monitoring scheme

3. The consortium concluded that whilst the UK is rich in soils data at a range of relevant spatial and temporal scales, it is not possible to integrate and/or combine existing schemes to deliver the full requirements of a UK soil monitoring scheme due to problems with differences in methodology and timing of sampling. However, current schemes could provide a framework to establish a new scheme whilst providing information on indicators of soil quality during a transition period. Existing schemes could also provide data to help interpret and understand any changes observed whilst running alongside a new UK scheme. A second option would be to select of one of the existing schemes with the recommended statistical design and operating at country or GB level and to expand it so that all soil indicators were included with reporting at country-level and UK level with the required contextual information. Whatever approach is taken, the exact purpose and required outcomes of a UK-scale soil monitoring scheme will need to be carefully specified to ensure that the design meets all expectations/needs.

4. The consortium recommends that any new UK scheme should contain two distinct elements. Firstly, a surveillance element with broad spatial coverage would need to be designed to allow changes of specific sizes in specific regions to be detected with known power. This element would have to be statistically robust and be capable of detecting changes as a result of changing land use / cover patterns. Sampling locations could either be grid-based or random but in either case a known sampling frame would be required. One option in any new UK monitoring scheme might be to adopt a rotating panel design in which sampling locations are dropped after a period of time to ensure representativeness of the population for which inferences are required. Secondly, contextual information would be required to allow changes measured by the surveillance element to be understood and interpreted. Without this second element, the causes and hence policy implications of changes detected by the surveillance element would be open to challenge.

Key words: soil, monitoring, indicators, soil carbon, UK-SIC, soil function, soil threats

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LINKED DATA CATALOGUE
SNIFFER Soil Monitoring Catalogue Nov 2006 (LQ09).xls

1. INTRODUCTION

The UK-Soil Indicators Consortium (UK-SIC) ultimately aims to identify i) indicators of soil quality for monitoring and ii) the design of a soil monitoring scheme for the UK. This project sits mid-way between these two stages with the objective of informing the development of a subsequent project whose purpose will be to design a UK soil monitoring scheme. The primary objectives of project LQ09 are to assess what schemes are currently in place (UK and EU), which indicators they address and whether existing datasets could fit into a UK network for soil monitoring. The main activities were therefore to construct a catalogue of existing schemes and to code these against standardised criteria which reflect their potential value for a UK soil monitoring scheme with reporting ability at a devolved administration level. All current schemes were then evaluated for their strengths, weaknesses, opportunities and threats (SWOT analysis) to identify the opportunities and constraints of integrating or combining current schemes to deliver a UK soil monitoring scheme.

2. CATALOGUE OF UK SOIL MONITORING SCHEMES

The catalogue of UK soil monitoring schemes has been designed to provide extensive information on current projects with soil monitoring as their primary focus together with relevant studies that have recently been completed or closed. This includes infrequent spatial surveys (e.g. the National Soil Inventory) as well as monitoring networks where sampling frequency varies according to the measurement being made (e.g. Environmental Change Network). The classic long-term study at Rothamsted has also been included because of the exceptional nature of this experiment and its remarkable length of time-series data. Inclusion was justified on the basis that the study can provide context and perspective to shorter, but more spatially extensive studies. The long-term sludge trials and the Soil QC study run by ADAS were also included as they have a network of sites (9 for the sludge trials and 7 for Soil QC) which include untreated control plots at which the same suite of measurements are made. In effect this provides a nationally distributed set of monitoring sites.

There are a large number of long-term experimental sites in the UK within the agricultural, environmental and forestry research sectors which include soil measurements as part of their study protocol. For example, Morecroft et al., (2005) provide an inventory of eleven experimental sites used to investigate the effects of atmospheric nitrogen deposition on semi-natural, terrestrial ecosystems. It is clear from this example that the sites have very varied suites of measurements often accompanied by limited soils information. They rarely share common measurement protocols. It is therefore difficult to link such sites to form a virtual monitoring network. For these reasons, such projects have been excluded from the catalogue.

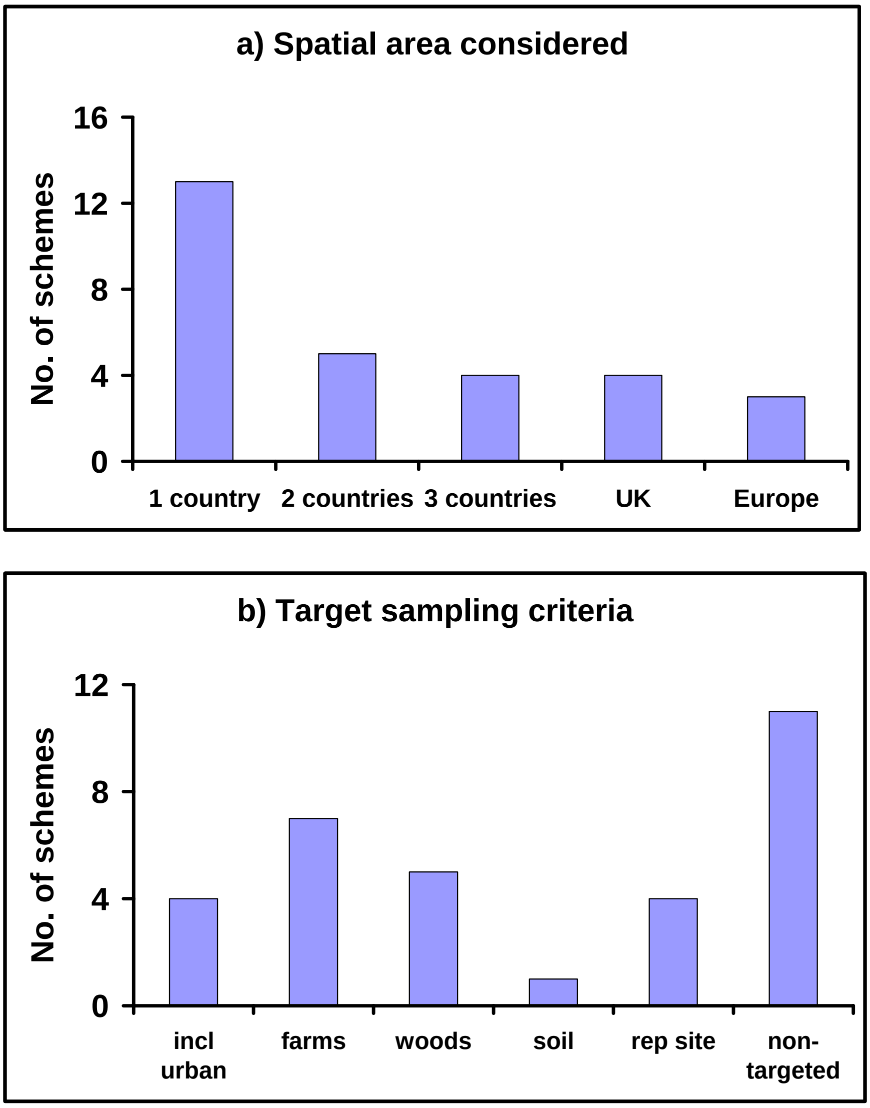
The catalogue was designed taking into account inputs from the project steering group and members of the research consortium. A proforma version of the catalogue was circulated to monitoring scheme operators identified by members of the research consortium as well as to individuals identified from sources provided in the Tender specification and on various websites. The recent project undertaken by ADAS on behalf of the Environmental Research Funders Forum (ERFF; Slater et al., 2006), which summarises all UK terrestrial and freshwater environmental monitoring schemes, was consulted, along with the soils meta-database compiled for Defra by ADAS.

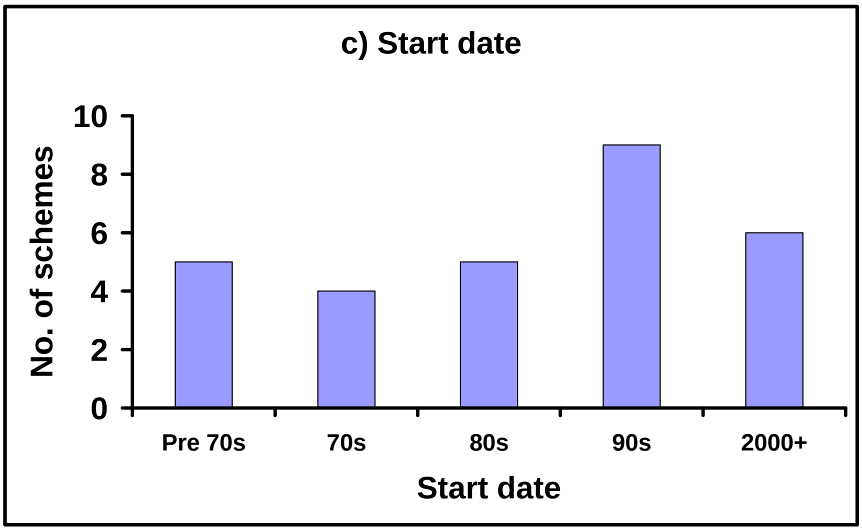
The data catalogue has been compiled in MS Excel and is available on the CD-rom accompanying this report or on the SNIFFER website (www.sniffer.org.uk).

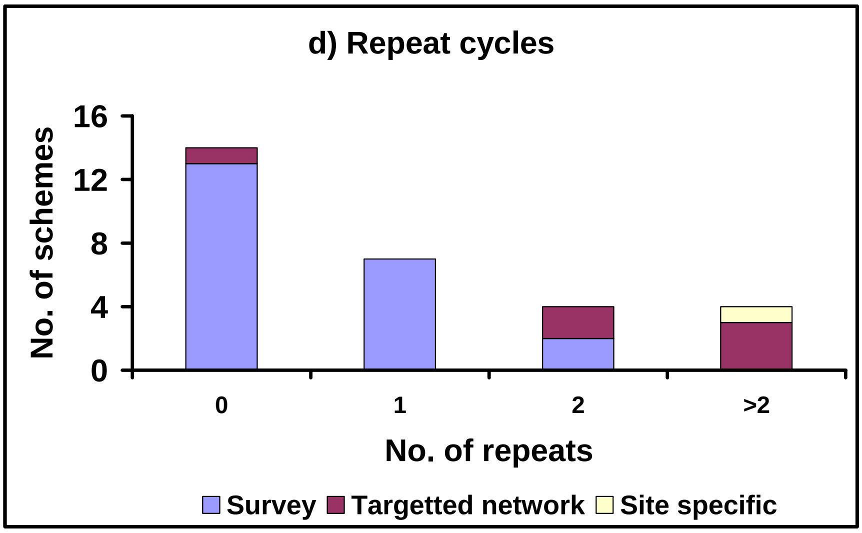
2.1 Analysis of catalogue entries using criteria codes and text entries

A total of 29 schemes are reported in the catalogue from 30 requests for information. Of these, 21 are still open and ongoing, five are closed or completed and three are closed pending funding. A list of the 29 schemes and their abbreviations is listed in Appendix 1.

Figure 2.1 Summary plots for selected catalogue entries



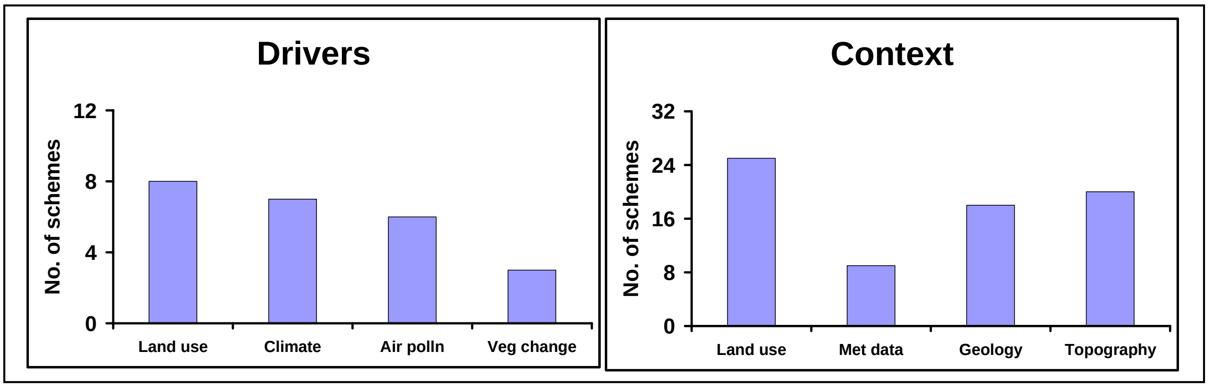




The majority of the schemes in the catalogue cover only one country which reflects the contribution from the individual surveys within Scotland and Northern Ireland (Figure 2.1). There are synergies hidden within this statistic as, for example, GSNI Tellus (Northern Ireland) is a comparable scheme to G-BASE (GB). Only four surveys include urban areas, although the majority of schemes, which exclude urban areas, cover all habitats and land use types. Perhaps surprisingly, most schemes were started in the 1990s which may help to explain why the majority of surveys have no repeat cycle of measurements. The majority of schemes with repeat cycles of measurements are networks such as ECN and the Rothamsted experimental site. The NSI and CS have one repeated cycle of measurement and the RSSS, which is now closed, had two. Of the surveys with repeated measurements, only the RSSS and the soil structural survey move sites between surveys. Only the ECN network uses permanent markers to re-locate sites, the remainder relying equally on national grid references or Global Positioning Systems (GPS).

The number of broad contextual parameters reported for schemes varies widely between 1 and 15, with information on land use being reported by virtually all schemes (Figure 2.2). Excluding those surveys primarily reporting on baseline conditions (e.g. G-BASE), the numbers of drivers of change recorded also cover a wide range between 1 and 22. The majority of schemes (16) report between one and five drivers, spread equally between land use/management and climate with fewer reporting on air pollution and vegetation change.

Figure 2.2 Summary plots for contextual parameters and drivers of change.



Of the schemes providing information on access to data, approximately two thirds require a licence for the data (with or without a charge) and the remainder are freely accessible without licence agreements. All the schemes hold data in modern digital formats, with about 70% of those providing information claiming complete data records.

2.2 Other monitoring data catalogues and meta-data

There have been several recent projects that have endeavoured to draw together meta-data or catalogues of environmental monitoring schemes in the UK. The majority of these have attempted to cover the entire spectrum of environmental monitoring ranging from items such as air quality and remote sensing to marine mammals and plankton recording. The projects have considered regions (e.g. Snowdonia candidate-SAC; Reynolds et al., 2005a), individual countries (e.g. Wales baseline monitoring database; Reynolds et al., 2005b) and the whole of the UK (Strategic analysis of UK environmental monitoring activity for ERFF; Slater et al., 2006). Together they provide a valuable information resource of strategic importance within their specified remits. Inevitably because these projects are trying to cover such a broad range of monitoring activities, the entries for particular soil monitoring schemes are less detailed than those contained within this more focused catalogue commissioned by SNIFFER. The SNIFFER catalogue also provides a greater depth of information in some aspects compared to the earlier ADAS-Defra soil monitoring data base with, for example, more detail provided on sampling scheme designs and the archiving of data and samples.

Information relevant to soils can also be obtained indirectly from water quality monitoring data; one of the most obvious cases being suspended sediment monitoring as an indicator of soil erosion. There is a large amount of water quality monitoring activity in the UK; monitoring of the freshwater environment (including hydrology and ecology) accounted for a third of the entries in the ERFF database and these activities were dominated by the Environment Agency, SEPA and the Environment and Heritage Service, Northern Ireland (Slater et al., 2006). Fifty seven monitoring schemes are listed in the ERFF database under the topic of ‘freshwater chemistry’ covering a wide range of activities from individual site specific monitoring (e.g. Beddgelert Forest, Plynlimon), monitoring networks (e.g. the Acid Waters Monitoring Network) to the more extensive monitoring programmes determined by legislative and other policy drivers. Unfortunately, the majority of the nationwide schemes operated by regulatory organisations did not state which measurements were actually made. The entries simply contained statements such as “7 freshwater chemistry determinands measured” with no further elaboration. Furthermore, some aspects of water quality monitoring are currently being reviewed in the light of the requirements of the Water Framework Directive, so that some schemes may change in the relatively near future.

Much of the water quality monitoring undertaken by the regulatory agencies outlined above is driven by legislation at national and European level. The broad focus tends to be either on pollution prevention and control or the maintenance of quality standards for particular water uses. This is reflected in the suites of measurements of the various schemes and the location of most monitoring sites in river reaches away from the headwaters. Thus for example, the National Water Quality Classification for Scotland includes all rivers with a catchment area greater than 10 km^2; smaller rivers are only included where a pollution problem is known to exist. For large catchments it can be difficult to attribute signals in the data to specific sources, and soil may only be one of many possible candidates. For small to medium sized river basins solute concentrations in runoff will reflect more localised source areas, although point sources can still confound the relationship between land use and water quality. Data from schemes such as the Environment Agency General Quality Assessment which has approximately 7000 monitoring sites across England and Wales, have been used to generate regional maps showing the river water concentrations of individual chemicals (e.g. for nitrate Betton et al., 1991; for phosphorus Muscutt and Withers, 1995). Figures 2.3 and 2.4 show the data from Environment Agency monitoring points for suspended sediment concentrations in Welsh rivers as individual points (Figure 2.3) and as interpolated areas (Figure 2.4). This illustrates the value of these data in providing a broad overview of sediment concentrations in surface waters highlighting areas of concern. Another step is required before this information can be interpreted directly in relation to specific land and soil management practices. However, the data do provide contextual information for soil monitoring and could be used for targeted monitoring of problem areas.

However, it must be remembered that the data collected at a water quality monitoring point is an aggregate measure of all the influences in the upstream catchment. Thus the use of water quality parameters to monitor changes in soils has to be approached very carefully in order to obtain information that can be interpreted unequivocally in relation to soils. This would require careful scheme design and site selection with the requirements and objectives of soil monitoring being considered ahead of those for monitoring the state of the aquatic environment, which is the natural focus of most water quality monitoring schemes.

Figure 2.3 Map of suspended sediment concentrations at individual sampling points in Welsh rivers (from Reynolds et al., 2004)

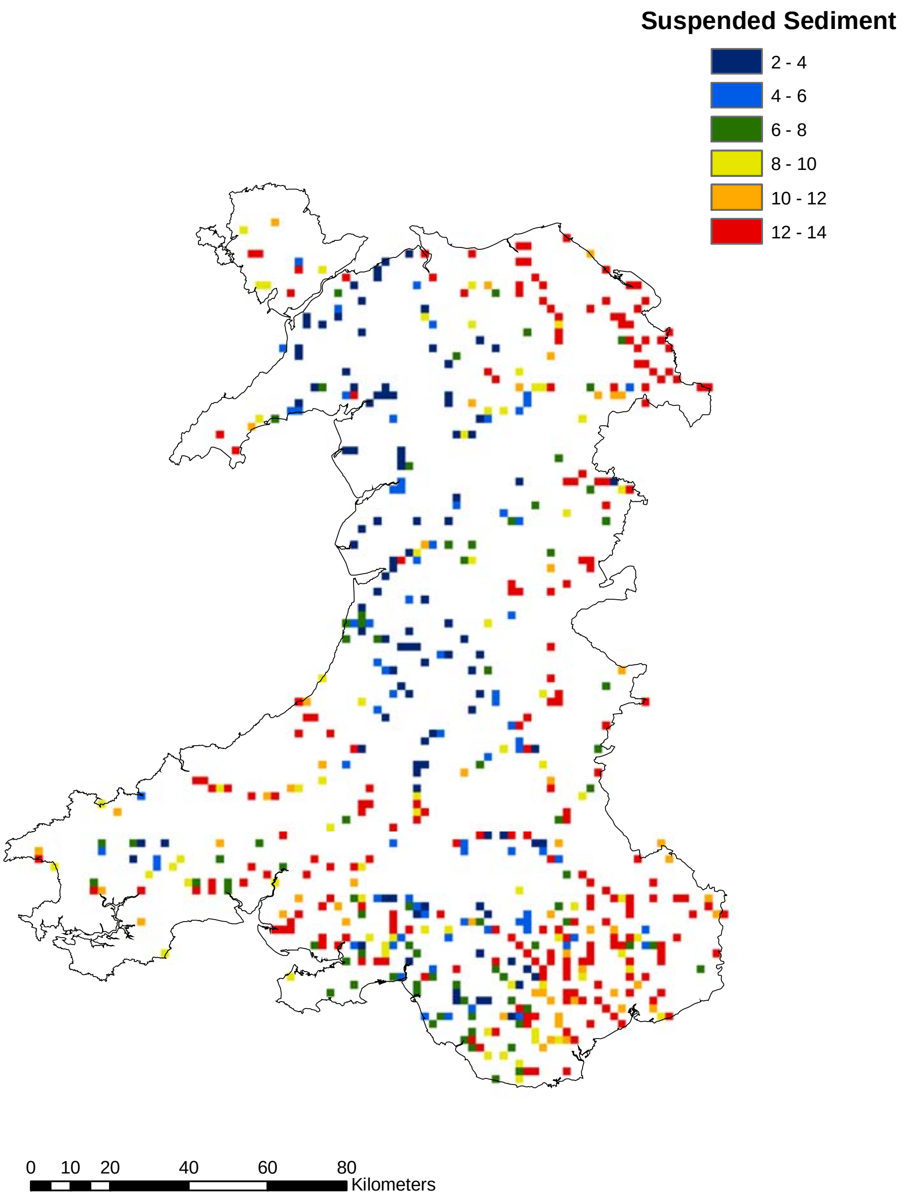
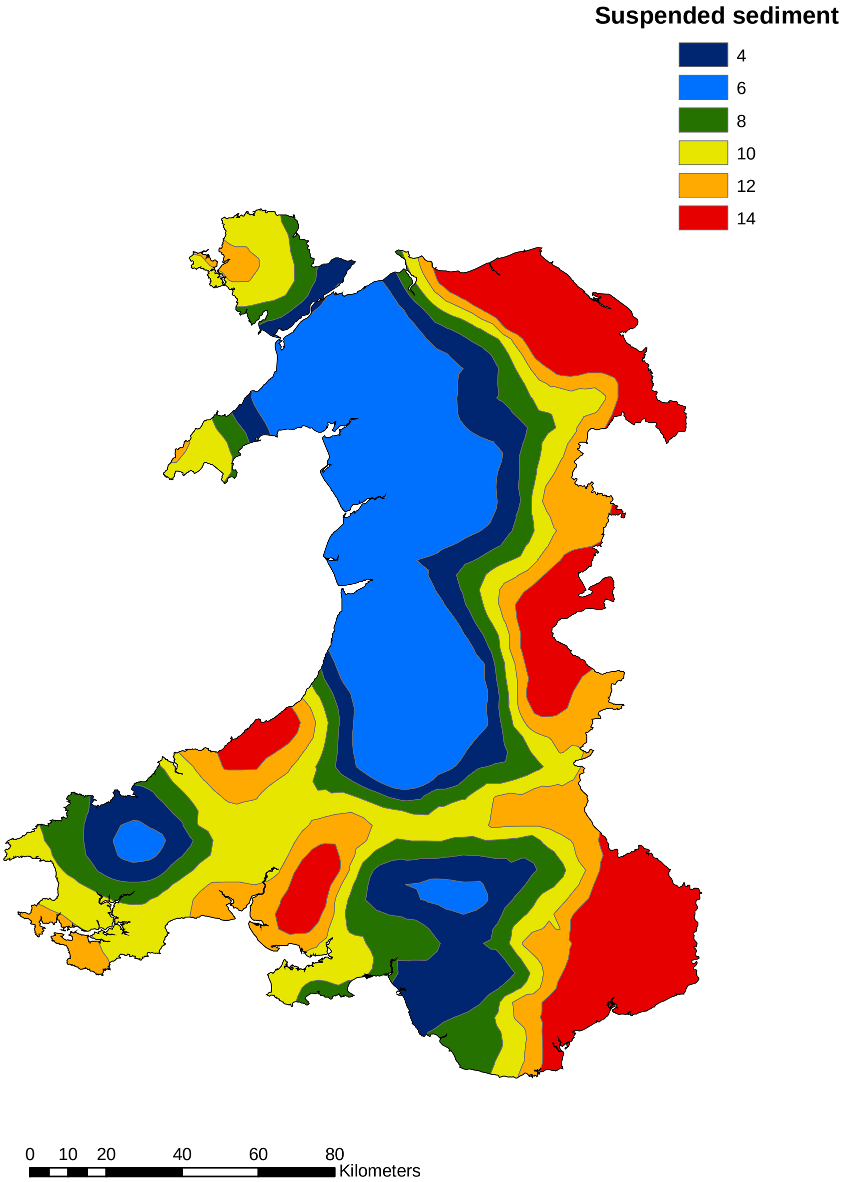


Figure 2.4 Map of suspended sediment concentrations in Welsh rivers interpolated from the point data in Figure 2.3 using geostatistics



3. CRITERIA FOR CODING CURRENT SCHEMES

The entries in the catalogue were coded to enable overviews to be compiled. The use of codes not scores was employed to remove the possibility of value judgements in the interpretation of the catalogue entries. Some of the scheme details were not coded, either because it was not appropriate (for example Name, Purpose, etc.) or because the requirement for extended description precluded the allocation of a single code (for example details of laboratory and field methods). In addition the following codes were used:

0 indicates code zero as described in the coding table
NA indicates not applicable
NIP indicates no information provided

The codes are presented Appendix 2.

4. LINKAGES BETWEEN AVAILABLE SOIL DATA AND INDICATORS OF SOIL QUALITY

4.1 Functions of soil

There has been considerable interest in recent years, both in the UK and internationally, in the development of robust and interpretable indicators of soil quality that can inform on the capacity of soil to deliver its various functions. A basic principle in soil protection, that will be adopted in the forthcoming EU Soils Framework Directive, is that this should work towards the preservation of soil functions. There are several definitions of soil functions in current usage but for this project, we adopted definitions of soil functions which have had widespread use within the UK-SIC and UK Government Agencies/ Departments in general and are recognised under the EU Thematic Strategy for Soil Protection.

The functions of soil are:

- Food and fibre production
- Environmental interaction (between soils, air and water)
- Support of ecological habitats and biodiversity
- Protection of cultural heritage
- Providing a platform for construction
- Providing raw materials

4.2 Indicators of soil quality

Indicators of soil quality should inform on how well soil is performing these functions. This includes not only the primary human use of the soil (e.g. crop production) but also the delivery of, and the capacity to maintain, other functions e.g. provision of a healthy water supply or protection of buried artefacts. Soil functions are, in effect, higher-level descriptions of a range of ecosystem services required from soil. There is considerable overlap in the requirements for ecosystem services across soil functions e.g. support of ecological habitats and biodiversity requires similar ecosystem services to food and fibre production but each requires these services to different degrees which are set, for example, by different plant requirements for germination and growth. Robust indicators of soil quality therefore need to be developed in the context of these differing requirements for ecosystem services.

Since 2003, the UK-SIC has supported several reviews on indicators of soil quality for specific soil functions. These reports have been used to support the assessment undertaken in this project. By addressing the relevance of indicators of soil quality to specific functions, it is implicit that the indicators will be assessing the delivery of ecosystem services, even if the related services have not been explicitly stated. A full list of the indicators recommended by these reviews is presented in (Table 4.1) along with a sub-set currently prioritised by the UK-SIC as a likely MDS along with the Defra headline indicator of soil organic matter content. It is acknowledged that this MDS has not been finalised and may be subject to change by UK-SIC. In addition, there are several other projects and initiatives addressing indicators of soil quality. We have also included the current recommendations from an EU project (ENVASSO) which has specifically addressed the links between indicators and threats. Note that indicators relating to chemical elements refer to element concentrations in the soil and not total stock.

4.3 Soil organic matter - a headline indicator of soil quality

The Sustainable Farming and Food Strategy (SFFS) for England and Wales has published a list of indicators to monitor sustainability in farming and food. The SFFS considers topsoil soil organic matter as a headline indicator for the better use of natural resources. The target is to halt the decline of soil organic matter (SOM) caused by agricultural practices in vulnerable soils by 2025, whilst maintaining, as a minimum, the soil organic matter of other agricultural soils, taking into account the impacts of climate change. The SFFS and UK-SIC indicator has currently been set for topsoil only (0 to 15 cm) and with respect to the concentration of carbon. The EU Envasso project proposed total carbon stock (full profile assessment) as an indicator for soil carbon as well as topsoil carbon content. Stock has not been considered in this context although some schemes could assess both; see catalogue for where profile and bulk density measurements have been made alongside topsoil measurements of carbon concentration.

Although the headline indicator has been derived from soil organic carbon (SOC) measurements using the Walkley Black analytical method, SOM can be assessed reliably from other analytical methods for either SOC or SOM. Therefore, Table 4.1 presents the soil carbon indicator as a measurement of either SOC or SOM since it has been assumed, where reliable methods have been used in schemes, that either can be used to assess SOM status and change. However, to report on total SOC content (as opposed to simply concentration) a measurement of bulk density and depth is required which is absent from several current schemes.

4.4 Threats to soil

Certain events or processes that degrade soil have been identified as “threats” to soils in Europe and all but one of these are detailed in Figure 4.1; halting the loss of biodiversity is not directly included at present, but actions on threats will be set to contribute to halting biodiversity loss by 2010 through other mechanisms e.g. Natura 2000 etc. Member states will be required to identify areas at risk from these threats e.g. through the use of existing monitoring schemes. Work is on-going to identify indicators of soil quality that can be used to assess areas at risk from these threats. One such example is the EU-funded ENVASSO project (Eckelmann et al., 2006). The ENVASSO list of soil indicators (accurate at the time of publication of this report), which have been deemed suitable for assessing individual threats, has been related to the UK-SIC indicators (see Table 4.1). In addition, the research consortium has identified other UK-SIC indicators that are relevant to assessing soil threats (see Table 4.1).

Figure 4.1 Soil threats addressed by the proposed EU soil framework directive (European Communities, 2006).

Table 4.1 List of soil quality indicators obtained from reports to UK-SIC and the relevance of these to individual soil functions and threats.

A = UK-SIC indicators currently in the MDS; R = recommended primary indicators1
S = recommended but not taken forward1; O = recommended for further research1
B = biological indicators prioritised for each function2; E = indicators proposed by the EU FP6 funded ENVASSO project to assess the EU priority threats to soil; T = indicators relevant to functions/threats, as assessed by this project

Current list of UK-SIC Indicators	**functions of soil**									**EU threats to soil**								
	SOM: headline indicator	UK-SIC indicators; agreed to date	Food & fibre production	Environ-mental interactions	Support for ecological habitat & biodiversity	Provision of raw materials	Cultural heritage & archaeology	Platform: *Built environment*	Biological indicators[2]	decline in SOM[6]	soil contamination	soil erosion	soil compaction	landslides	soil salinisation	decline in soil biodiversity[4,5]	sealing	desertification
topsoil soil organic matter content/SOC	H	A	R	R	R		R			E								T
extractable Mg		A	R															
extractable K		A	R		R													
total Cd		A	R								E							
soil moisture at 1 m depth		A	R															T
bulk density		A	R	R						T			E					
Olsen P		A	R	R	R													
soil pH		A	R	R	R		R				T				T			
total Cu		A	R	R							E							
total N		A	R	R														
total Ni		A	R	R							E							
total Zn		A	R	R							E							
topsoil aggregate stability		A	R									T	T					T
C/N ratio		A			R					T								
potentially mineralisable N		A			R													
available Cu				S							T							
available Ni				S							T							
available Zn				S							T							
area & volume of superficial deposits lost annually[3]							O											
area of new cultivation							O											
erosion and sediment distribution							O					T		T				
plough depth							O											
water-table depth and variability							O											T
soil redox							O				T		T		T			
ammonia oxidisers/denitrifiers			B	B	B				O							T		
Archaea				B	B				O							T		
bacterial community structure (TRFLP)			B	B	B				O							T		
fungal community structure (TRFLP)			B	B	B				O							T		
methanogens/ methanotrophs (TRFLP)				B	B				O							T		
microarthropod community structure			B	B	B				O							E		
multiple substrate induced respiration (MSIR)			B	B	B				O							E		
nematode community structure			B	B	B				O							T		
on site visual recording - flora and fauna			B	B	B				O							T		
potential (multiple) enzyme activities			B	B	B				O									
soil microbial biomass & community structure (PLFA)			B	B	B				O							T		

1. Information derived from review reports to UK-SIC
2. Derived from Black et al., (2006)
3. Area & volume of superficial deposits lost annually to mineral extraction & peat cutting
4. ENVASSO: Collembola component of the microarthropod community as mandatory and mites as voluntary
5. ENVASSO: basal and glucose induced respiration (as component of MSIR)
6. Bulk density included as "T"; not an indicator of carbon itself but included as an essential measurement to derive carbon stock

4.5 Available soil data

Each soil monitoring scheme provided a list of soil properties measured for the catalogue. This information was used in a scoring system to support an objective assessment of the linkages between available soil data, soil functions/ threats and the indicators identified by UK-SIC. Where soil data are currently available for the UK-SIC indicators listed in Table 4.1, this was noted as 1 in the scoring system; data due in 2007/08 was denoted as 2. See Figure 4.2 for an extract of this information. This information was fed into a series of tables which counted and scored the availability of data for each indicator and function.

4.6 Results

Table 4.2 summarises the number of UK-SIC indicators relevant to each function, and the simple scoring system for the different indicator levels. From this, it can be seen that two functions currently have no UK-SIC indicators in place (provision of raw materials and platform) and only two indicators that address cultural heritage & archaeology. Biological indicators that are currently being piloted to address three functions (B) are not included in the scoring. Table 4.3 presents the results from the indicator scoring to functions and shows which schemes have data available on UK-SIC indicators as they relate to the different requirements; SFSS and each function. Table 4.4 present the results from scoring UK-SIC indicators to threats using a list from the ENVASSO project and also links identified by the research consortium.

Figure 4.2 An extract of the recording of available data against indicators

Name indicators 1 = data available for soil; 2 = near-future analyses from soils	ITE/NCC 'Bunce 1971' woodland survey	AFBI 5K PITS 1995	GSNI TELLUS 2004-06 (= BGS's G-BASE scheme in the rest of the UK).	BioSoil
Abbreviated name	NCC woods	5K 1995	TELLUS	BioSoil
SOM/SOC	1	1	1	1
extr. Mg		1		1
extr. K		1		1
total Cd		1	1	
moisture_1 m				
BD		1		1
Olsen P		1		
pH (H_2O)	1	1	1	1
total Cu		1	1	1
total N	1	1		1
total Ni		1	1	1
total Zn		1	1	1
agg. stab.				
C:N	1	1		1
pot_min_N				
avail. Cu		1		
avail. Ni		1		
avail. Zn		1		1
depos_lost				
new_cultiv				
erosion_sed				
plough depth				
water-table				
soil redox				
ammox/denitr				
Archaea				
bacterial_comm				
fungal_comm				
methanogens/trophs				
microarthropods				
MSIR				
nematodes				
visual flora_fauna				
enzymes				
PLFA				

Table 4.2 Indicator level, indicator score and number of indicators per soil function.
A = UK-SIC indicator; H = Defra headline indicator;
R = UK-SIC recommended primary indicators
S = UK-SIC recommended but not taken forward;
O = UK-SIC recommended for further research
B = UK-SIC biological indicators prioritised for each function

Indicator level	**Indicator score**	SOM: headline indicator	UK-SIC agreed to date (MDS)	Food & fibre production	Environmental interactions	Support for ecological habitat & biodiversity	Provision of raw materials	Cultural heritage & archaeology	Platform: *Built environment*	**total**
A			15	0	0	0	0	0	0	15
H	3	1		0	0	0	0	0	0	1
R	3	0		13	8	6	0	2	0	15
S	2	0		0	3	0	0	0	0	3
O	1	0		0	0	0	0	6	0	17
TOTAL		1		13	11	6	0	8	0	35
B		0		9	11	11	0	0	0	

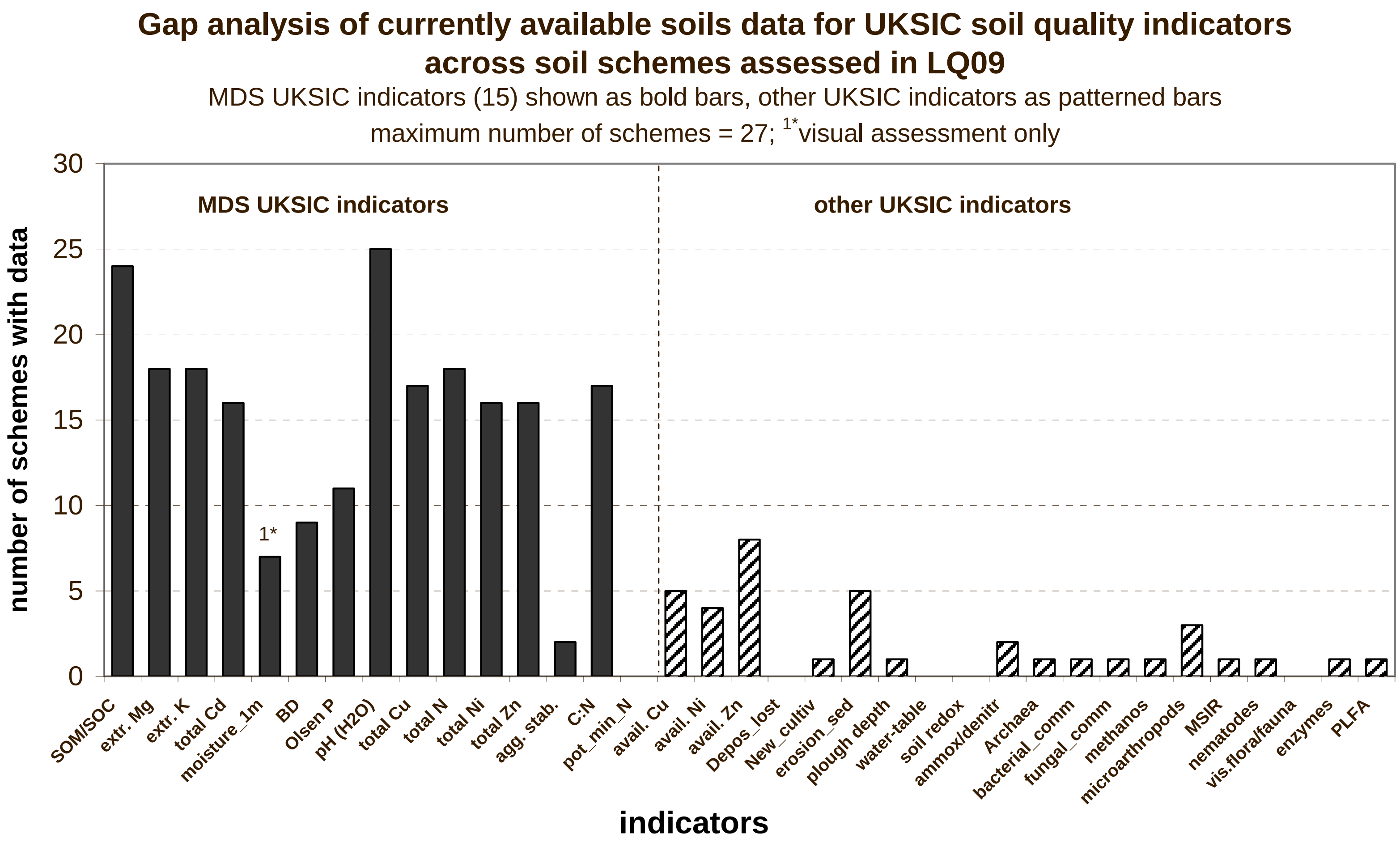
Table 4.3 Number of UK-SIC indicators in different soil monitoring schemes and scores for indicators classified by soil functions.

Indicators	INDICATOR GRADE	NCC woods	CS	RSSS	RothRes LTEs	NSI	Soil struct.	AFBI 5K 1995	AFBI 5K 2005	AFBI 1K 1995	RSSS(NI)	TELLUS	NSIS + NipAqua	RSPS	SSMUTS	TIPSS	Grids_Scot	G-BASE	GSUE	FOREGS	ECN	BioSoil	Level I	Level II	Sludge	SOIL-QC	NSRI_RSP	UK_SHS	CS2007	NSIS_2007
Number of UK-SIC MDS indicators	A	4	9	4	10	10	2	12	8	8	8	6	11	7	7	7	7	6	6	6	12	10	11	11	10	7	8	7	11	13
Number of UKSIC indicators		4	11	4	15	13	3	15	8	11	8	6	12	8	8	7	8	6	6	6	13	11	12	12	22	7	8	7	22	23
Number of other UKSIC indicators		0	2	0	5	3	1	3	0	3	0	0	1	1	1	0	1	0	0	0	1	1	1	1	12	0	0	0	11	10
Functional scores for UKSIC indicators																														
Defra Headline Indicator SOM (SOC)	H	3	3	0	3	3	0	3	3	0	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Food & fibre production	R	9	24	12	27	30	6	33	21	24	21	18	30	18	18	18	18	18	18	18	33	27	30	30	27	21	21	21	39	36
	S																													
	O																													
Environmental interactions	R	9	21	6	18	18	0	24	15	15	15	15	18	9	9	15	9	15	15	15	24	21	21	21	18	12	12	18	22	24
	S	0	0	0	6	6	0	6	0	6	0	0	0	0	0	0	0	0	0	0	0	2	2	2	4	0	0	0	0	0
	O																													
Support for ecological habitat and biodiversity	R	9	9	9	15	12	0	15	15	9	15	6	15	12	12	6	12	6	6	6	15	12	12	12	15	12	12	6	15	15
	S																													
	O																													
Provision of raw materials	R																													
	S																													
	O																													
Cultural heritage & archaeology	R	6	6	3	6	6	0	6	6	3	6	6	6	6	6	3	6	6	6	6	6	6	6	6	6	6	6	6	6	6
	S																													
	O	0	1	0	1	0	1	0	0	0	0	0	1	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	1	1
Platform:_*Built environment*	R																													
	S																													
	O																													
Biological indicators	R																													
	S																													
	O	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	10	0	0	0	10	9
TOTAL_SCORES_FUNCTION																														
Food & fibre production	ALL	9	24	12	27	30	6	33	21	24	21	18	30	18	18	18	18	18	18	18	33	27	30	30	27	21	21	21	39	36
Environmental interactions	ALL	9	21	6	24	24	0	30	15	21	15	15	18	9	9	15	9	15	15	15	24	23	23	23	22	12	12	18	22	24
Support for ecological habitat and biodiversity	ALL	9	9	9	15	12	0	15	15	9	15	6	15	12	12	6	12	6	6	6	15	12	12	12	15	12	12	6	15	15
Provision of raw materials	ALL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cultural heritage & archaeology	ALL	6	7	3	7	6	1	6	6	3	6	6	7	7	7	3	7	6	6	6	6	6	6	6	6	6	6	6	7	7
Platform:_*Built environment*	ALL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biological indicators	ALL	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	10	0	0	0	10	9
OVERALL SCORE_ALL FUNCTIONS		33	62	30	74	72	7	84	57	57	57	45	70	46	46	42	46	45	45	45	79	68	71	71	80	51	51	51	93	91

Table 4.4 Number of UK-SIC indicators in different soil monitoring schemes classified by soil threats using the ENVASSO approach(E) and other relevant indicators (T).

INDICATORS	INDICATOR GRADE	NCC woods	CS	RSSS	RothRes LTEs	NSI	Soil struct.	AFBI 5K 1995	AFBI 5K 2005	AFBI 1K 1995	RSSS(NI)	TELLUS	NSIS + NipAqua	RSPS	SSMUTS	TIPSS	Grids_Scot	G-BASE	GSUE	FOREGS	ECN	BioSoil	Level I	Level II	Sludge	SOIL-QC	NSRI_RSP	UK_SHS	CS2007	NSIS_2007
Number of ENVASSO threat-related UKSIC indicators	E	1	6	0	4	5	0	6	2	4	2	5	5	1	1	5	1	5	5	5	7	5	6	6	6	1	2	6	8	8
Number of other threat-related UKSIC indicators	T	2	2	1	6	4	2	5	2	4	2	1	3	3	3	1	3	1	1	1	2	3	3	3	11	2	2	1	9	10
Number of UKSIC indicators relating to individual soil threats																														
decline in SOM	E	1	1	0	1	1	0	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	T	1	1	0	1	0	0	2	2	0	2	0	1	1	1	1	1	0	0	0	2	2	2	2	1	0	2	1	2	2
soil contamination	E	0	4	0	3	4	0	4	0	4	0	4	4	0	0	4	0	4	4	4	4	3	4	4	3	0	0	4	4	4
	T	1	1	1	4	4	0	4	1	4	1	1	1	1	1	0	1	1	1	1	1	2	2	2	3	1	1	1	1	1
soil erosion	E																													
	T	0	0	0	0	0	2	0	0	0	0	0	1	1	1	0	1	0	0	0	0	0	0	0	0	1	0	0	0	1
soil compaction	E	0	0	0	0	0	0	1	1	0	1	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	1	1	1	1
	T	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
landslides	E																													
	T	0	0	0	0	0	1	0	0	0	0	0	1	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1
soil salinisation	E																													
	T	1	1	1	1	1	0	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1
deline in soil biodiversity	E	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	2	0	0	0	2	2
	T	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0	0	7	7
soil sealing	E																													
	T																													
desertification	E																													
	T	1	1	0	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1
Total number of UKSIC indicators for each soil threat																														
decline in SOM		2	2	0	2	1	0	3	3	0	3	1	2	2	2	2	2	1	1	1	3	3	3	3	2	1	3	2	3	3
soil contamination		1	5	1	7	8	0	8	1	8	1	5	5	1	1	4	1	5	5	5	5	5	6	6	6	1	1	5	5	5
soil erosion		0	0	0	0	0	2	0	0	0	0	0	1	1	1	0	1	0	0	0	0	0	0	0	0	1	0	0	0	1
soil compaction		0	0	0	0	0	1	1	1	0	1	0	0	0	0	0	0	0	0	0	1	1	1	1	0	1	1	1	1	1
landslides		0	0	0	0	0	1	0	0	0	0	0	1	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1
soil salinisation		1	1	1	1	1	0	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1
decline in soil biodiversity		0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	9	0	0	0	9	9
soil sealing		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
desertification		1	1	0	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1
Number of UKSIC indicators for threats per scheme		5	10	2	12	11	5	14	7	9	7	8	11	7	7	7	7	8	8	8	12	11	12	12	19	7	7	10	20	22

Figure 4.3


Gap analysis of currently available soils data for UKSIC soil quality indicators across soil schemes assessed in LQ09
MDS UKSIC indicators (15) shown as bold bars, other UKSIC indicators as patterned bars
maximum number of schemes = 27; 1* visual assessment only
MDS UKSIC indicators
other UKSIC indicators
number of schemes with data
indicators
0
5
10
15
20
25
30
1*
SOM/SOC
extr. Mg
extr. K
total Cd
moisture_1m
BD
Olsen P
pH (H2O)
total Cu
total N
total Ni
total Zn
agg. stab.
C:N
pot_min_N
avail. Cu
avail. Ni
avail. Zn
Depos_lost
New_cultiv
erosion_sed
plough depth
water-table
soil redox
ammox/denitr
Archaea
bacterial_comm
fungal_comm
methanos
microarthropods
MSIR
nematodes
vis.flora/fauna
enzymes
PLFA

4.7 Availability of data on UK-SIC indicators of soil quality from current schemes

Figure 4.3 shows a gap analysis of available data for UK-SIC indicators. This clearly shows that there are little or no data for two MDS indicators, aggregate stability and potentially mineralisable N, while moisture to 1 m, bulk density and Olsen P have been assessed from relatively few schemes; moisture to 1 m has not been measured in any scheme and only visually assessed from soil pits. SOM/SOC and soil pH (in water) have been measured in most schemes while the remaining MDS indicators have been measured in more than half the schemes. Thus there is a considerable amount of information available for the current MDS indicators, with the stated exceptions. As also shown in Figure 4.3 there is far less information currently available for the other UK-SIC indicators. Further data will become available post 2007/08, in particular for the biological indicators (see Table 4.3 and entries for CS2007 and NSIS2007).

The availability of data for the MDS UK-SIC indicators in each scheme is illustrated from the results presented in Figure 4.4. Most schemes have data available for 6 or more MDS UK-SIC indicators. Most national/regional scale schemes include data on a significant number of the MDS UK-SIC indicators (9 to 12). Figure 4.5 illustrates the results for the non-MDS UK-SIC indicators. Several schemes record 1 to 3 non-MDS indicators. Two schemes (RothRes LTEs and the Sludge Network) have data available on 5 and 12 indicators respectively; both schemes are intensive experimental sites.

4.8 Linkage of UK-SIC indicators to soil functions

Figure 4.6 shows the availability of data for individual functions from each scheme, based on the UK-SIC indicators listed for each function, including relevant biological indicators for food & fibre production, environmental interactions and supporting ecological habitats & biodiversity (see Table 4.1). It is interesting to see that most schemes have data relevant to the current range of functions for which UK-SIC indicators have been identified; there are currently no UK-SIC indicators for platform and provision of raw materials and therefore these have not been assessed further. In many instances, the relatively high level of available information is often due to one measurement being relevant to a range of functions, in particular SOM/SOC. Clearly the value of this information will be dependant upon having reliable/known thresholds or expected values for the different functions.

The results indicate that the greatest amount of information is available for indicators of food & fibre production, closely followed by environmental interactions. The availability of data is least for indicators of supporting ecological habitats & biodiversity.

For each scheme, a functional score was obtained from the number of indicators at each UK-SIC indicator level and the score attributed to that level (see Table 4.1). These functional scores for each scheme are shown in Figure 4.7; see also see Tables 4.2 and 4.3. This information further reinforces that most schemes have data available for each function. Only four schemes, as yet, have data on biological indicators; CS, ECN, RothRes LTEs and Sewage Sludge Network. The later three are intensive experimental/long-term sites, only CS is a national-scale scheme. Further data will become available from 2007/08, in particular for biological indicators (see Table 4.3 and entries for CS2007 and NSIS2007).

4.9 Linkage of UK-SIC indicators to soil threats

Figure 4.8 presents results from the gap analysis of available soil data for UK-SIC indicators as they relate to soil threats. The indicators have been grouped according to (i) a list available from the EU funded ENVASSO project (E) and (ii) by the research consortium as other relevant indicators (T). The results indicate that most schemes have some data available on indicators relevant to soil threats. However, this information is far less comprehensive than that for soil functions. Two schemes have most available data; ECN for the E-group indicators and the Sewage Sludge Network for the T-group indicators; the high T value for Sludge again highlights the inclusion of biological indicators. More data is available for the indicators being proposed by ENVASSO. This is not surprising given that data availability was one of the selection criteria for the ENVASSO project.

Figure 4.4

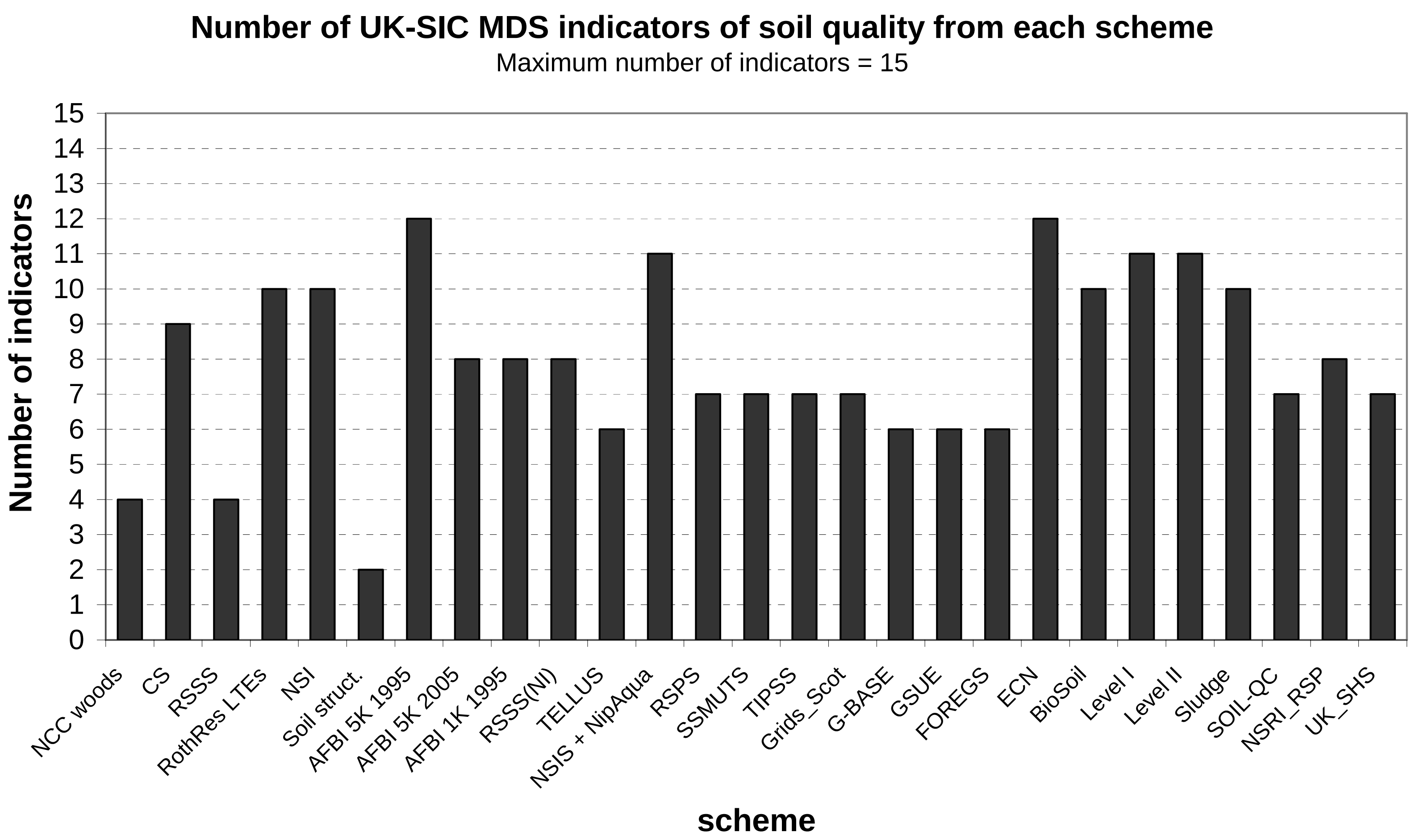

Number of UK-SIC MDS indicators of soil quality from each scheme
Maximum number of indicators = 15
Number of indicators
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
NCC woods
CS
RSSS
RothRes LTEs
NSI
Soil struct.
AFBI 5K 1995
AFBI 5K 2005
AFBI 1K 1995
RSSS(NI)
TELLUS
NSIS + NipAqua
RSPS
SSMUTS
TIPSS
Grids_Scot
G-BASE
GSUE
FOREGS
ECN
BioSoil
Level I
Level II
Sludge
SOIL-QC
NSRI_RSP
UK_SHS
scheme

Figure 4.5

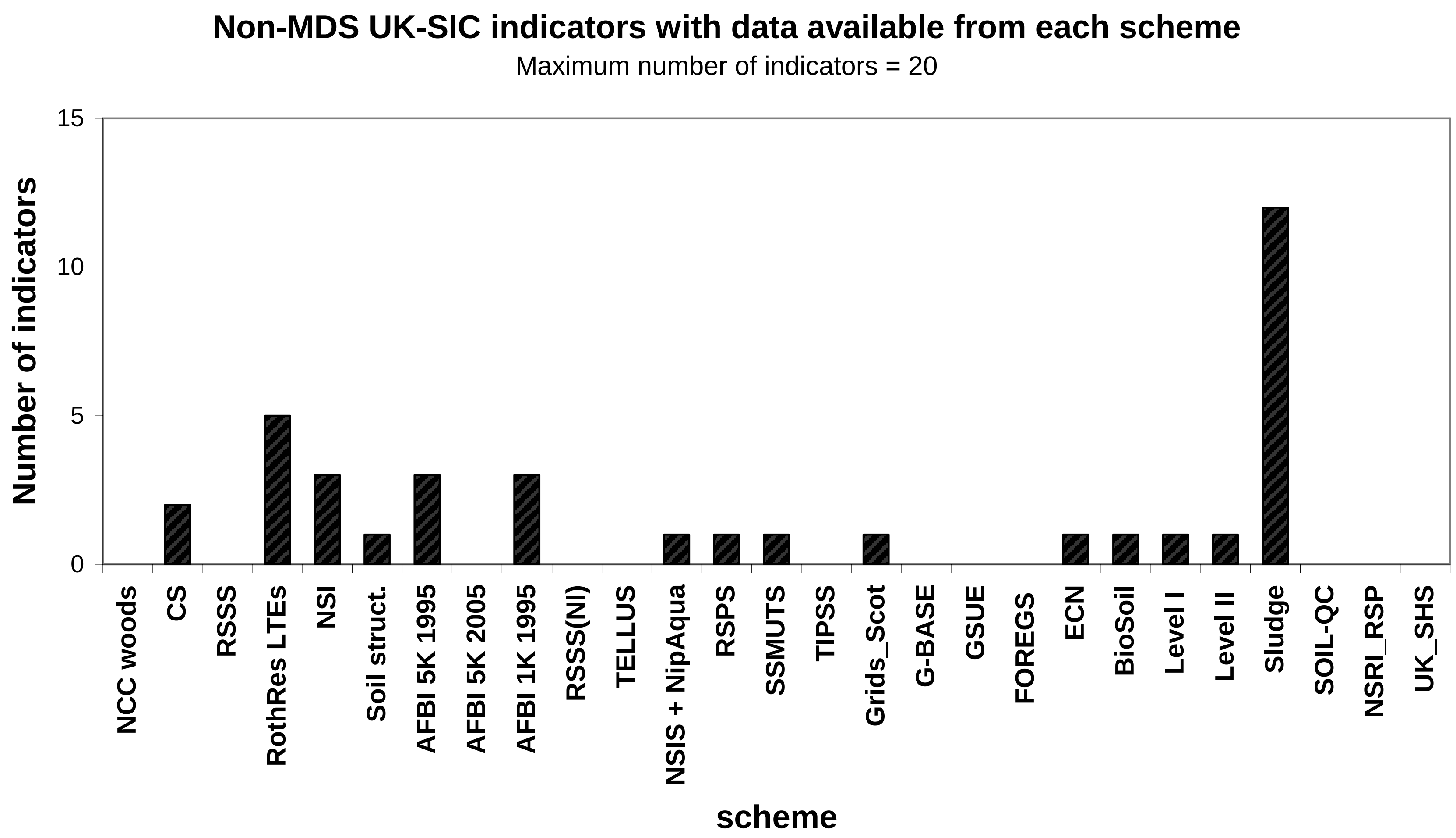

Non-MDS UK-SIC indicators with data available from each scheme
Maximum number of indicators = 20
Number of indicators
15
10
5
0
NCC woods
CS
RSSS
RothRes LTEs
NSI
Soil struct.
AFBI 5K 1995
AFBI 5K 2005
AFBI 1K 1995
RSSS(NI)
TELLUS
NSIS + NipAqua
RSPS
SSMUTS
TIPSS
Grids_Scot
G-BASE
GSUE
FOREGS
ECN
BioSoil
Level I
Level II
Sludge
SOIL-QC
NSRI_RSP
UK_SHS
scheme

Figure 4.6

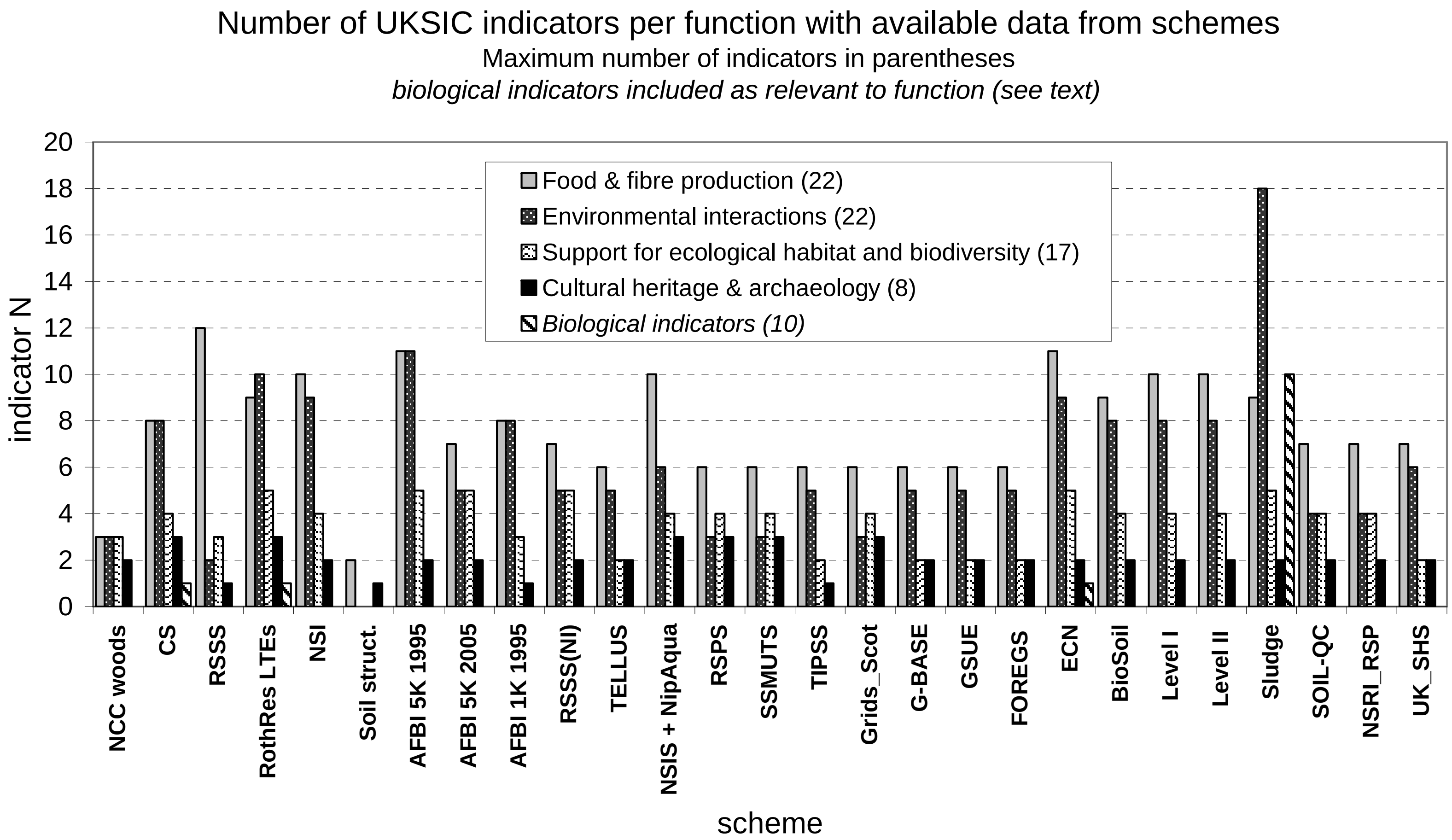

Number of UKSIC indicators per function with available data from schemes
Maximum number of indicators in parentheses
biological indicators included as relevant to function (see text)
indicator N
0
2
4
6
8
10
12
14
16
18
20
Food & fibre production (22)
Environmental interactions (22)
Support for ecological habitat and biodiversity (17)
Cultural heritage & archaeology (8)
Biological indicators (10)
NCC woods
CS
RSSS
RothRes LTEs
NSI
Soil struct.
AFBI 5K 1995
AFBI 5K 2005
AFBI 1K 1995
RSSS(NI)
TELLUS
NSIS + NipAqua
RSPS
SSMUTS
TIPSS
Grids_Scot
G-BASE
GSUE
FOREGS
ECN
BioSoil
Level I
Level II
Sludge
SOIL-QC
NSRI_RSP
UK_SHS
scheme

Figure 4.7

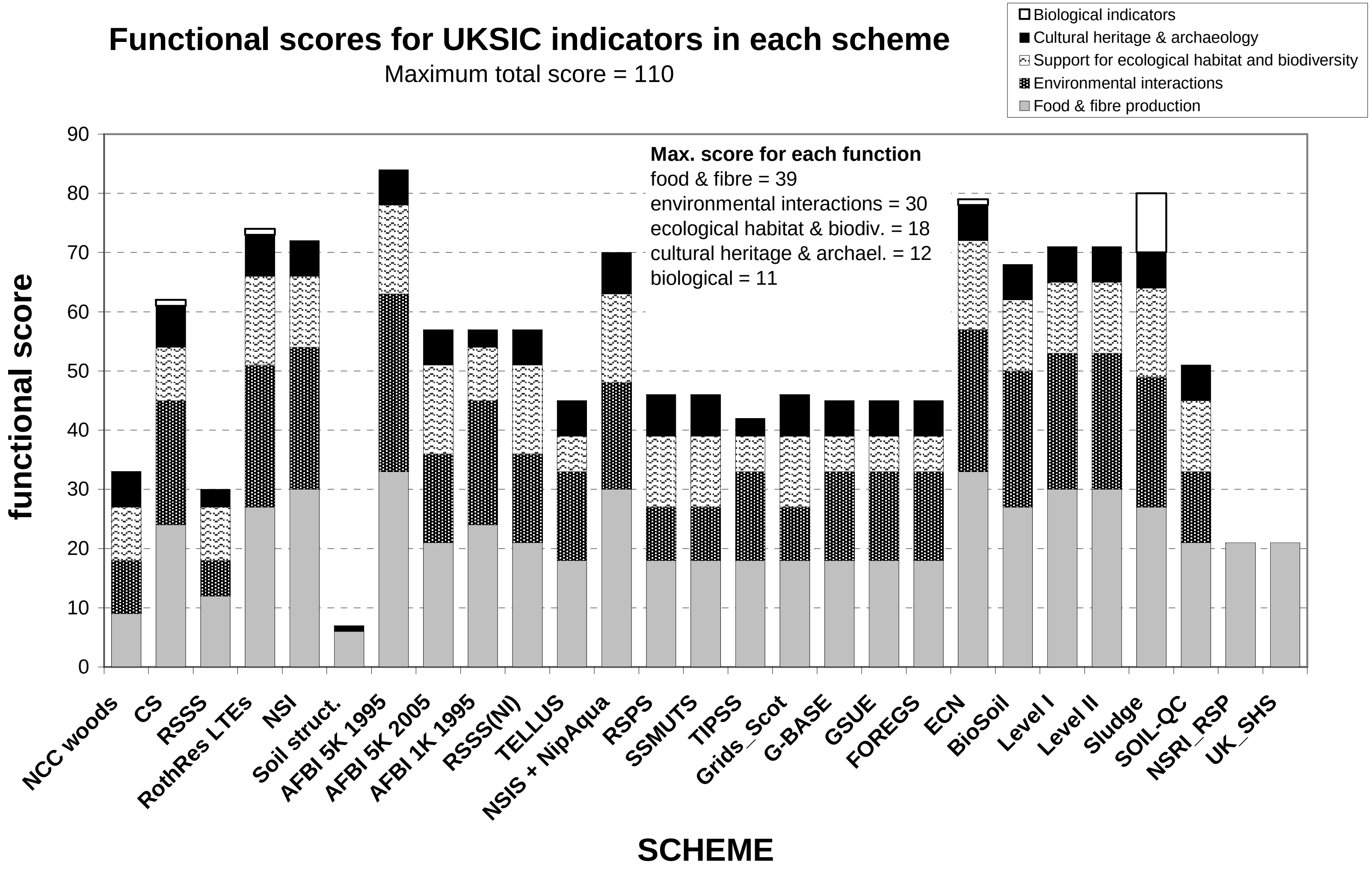
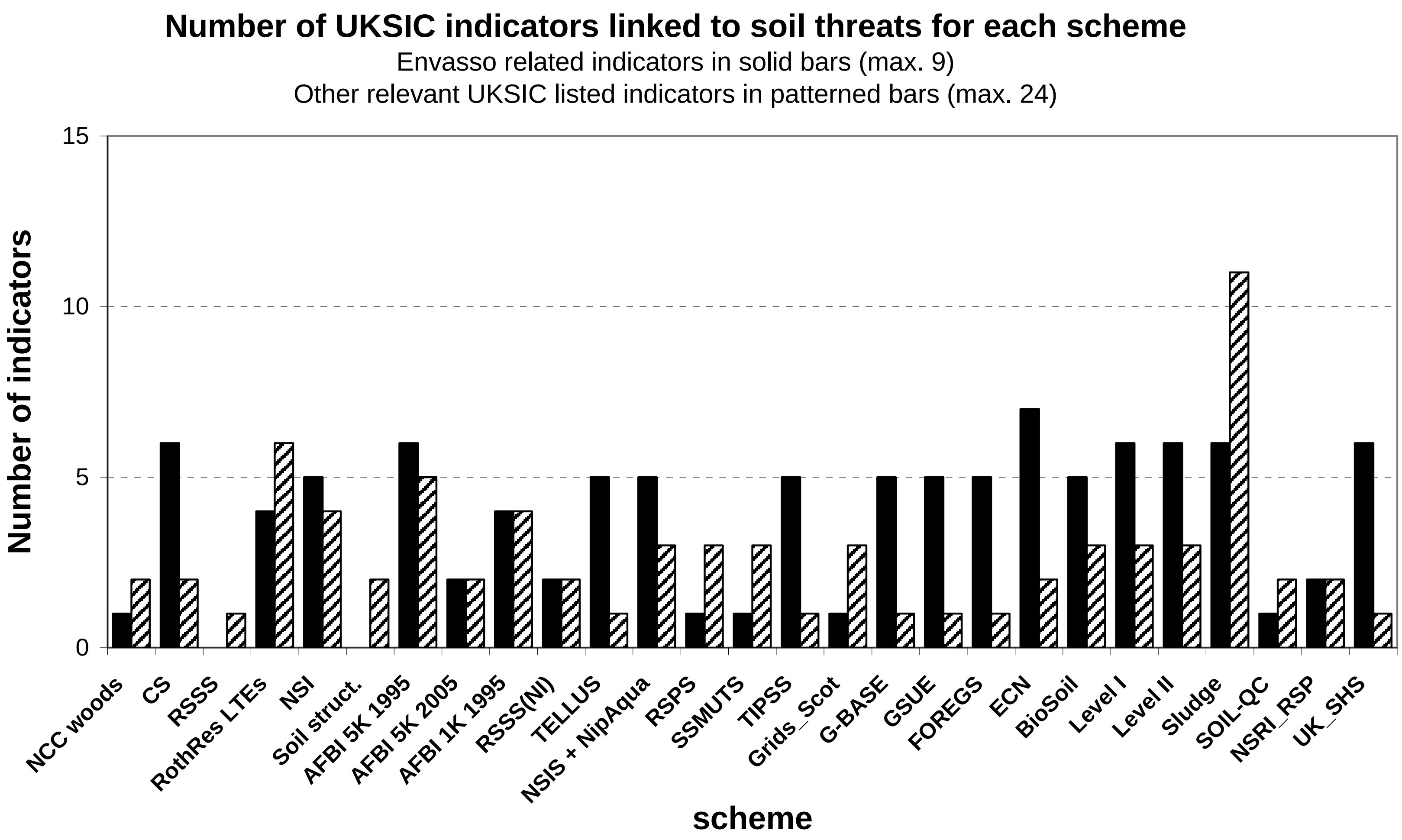

Functional scores for UKSIC indicators in each scheme
Maximum total score = 110
Biological indicators
Cultural heritage & archaeology
Support for ecological habitat and biodiversity
Environmental interactions
Food & fibre production
Max. score for each function
food & fibre = 39
environmental interactions = 30
ecological habitat & biodiv. = 18
cultural heritage & archael. = 12
biological = 11
functional score
0
10
20
30
40
50
60
70
80
90
NCC woods
CS
RSSS
RothRes LTEs
NSI
Soil struct.
AFBI 5K 1995
AFBI 5K 2005
AFBI 1K 1995
RSSS(NI)
TELLUS
NSIS + NipAqua
RSPS
SSMUTS
TIPSS
Grids_Scot
G-BASE
GSUE
FOREGS
ECN
BioSoil
Level I
Level II
Sludge
SOIL-QC
NSRI_RSP
UK_SHS
SCHEME

Figure 4.8


Number of UKSIC indicators linked to soil threats for each scheme
Envasso related indicators in solid bars (max. 9)
Other relevant UKSIC listed indicators in patterned bars (max. 24)
Number of indicators
scheme
0
5
10
15
NCC woods
CS
RSSS
RothRes LTEs
NSI
Soil struct.
AFBI 5K 1995
AFBI 5K 2005
AFBI 1K 1995
RSSS(NI)
TELLUS
NSIS + NipAqua
RSPS
SSMUTS
TIPSS
Grids_Scot
G-BASE
GSUE
FOREGS
ECN
BioSoil
Level I
Level II
Sludge
SOIL-QC
NSRI_RSP
UK_SHS

4.10 Conclusions following analysis of linkages between available soil data and indicators of soil quality

- A significant amount of soils data is already available for most MDS UK-SIC indicators. This information is available across a range of scales from single or multiple site long-term experiments (e.g. RothRes or ECN), regional/country-level (e.g. NSI, NSIS, AFBI) to national-scale surveys (e.g. BIOSOIL, CS).
- All schemes have some data available on the range of UK-SIC indicators; MDS and others. Most national-scale schemes have data available for 9 or more MDS indicators.
- Three MDS indicators have relatively little or no data currently available; potentially mineralisable N, aggregate stability and measured moisture content at 1 m.
- All available data for moisture content at 1 m are from visual assessments only
- The non-MDS UK-SIC indicators are not currently well represented across the schemes.
- Most schemes have data available on UK-SIC indicators relevant to soil functions (food & fibre production, environmental interactions, supporting ecological habitat & biodiversity and protection of cultural heritage).
- Protection of cultural heritage followed by supporting ecological habitat & biodiversity have the least amount of data available for relevant UK-SIC indicators
- Data on biological indicators is primarily available from long-term and/or intensive experimental sites.
- Data on indicators relevant to soil threats is relatively low compared to that for soil functions as this indicators were chosen to link to functions not threats. However available data does cover a range of scales from site-specific to UK-scale.
- Further relevant data will become available from planned sampling in 2007/08, in particular data on biological indicators.

5. STATISTICAL ISSUES FOR EVALUATING CURRENT SCHEMES AND CONSIDERATIONS FOR INTEGRATING AND/OR ADAPTING CURRENT SCHEMES

5.1 Sampling

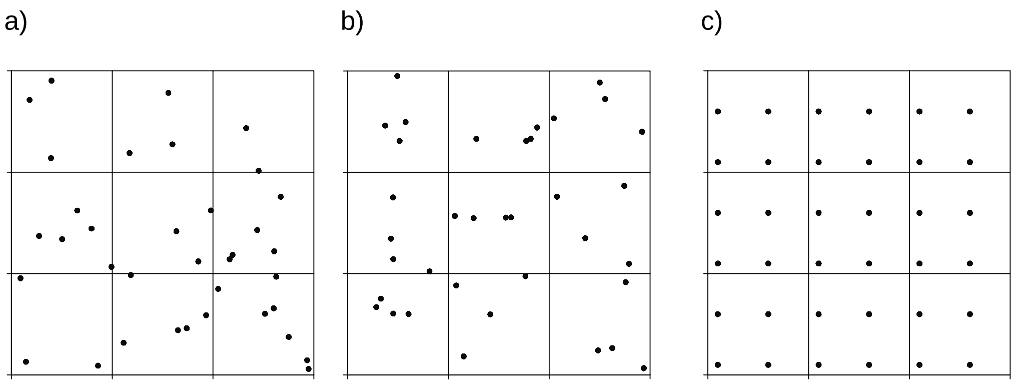
The first stage in establishing any sampling scheme is to identify the population to be studied. For some schemes this may be all the soils forming the land surface of the UK or one of the devolved administration areas (although it usually excludes urban soils), while other schemes may be limited to a particular land use (e.g. agricultural land or woodland). This is then followed by sample selection, measurement and estimation. Estimation may be based on a statistical model or may be design-based. In design-based estimation, estimates of means are obtained by weighting the observations by the inverse of the probabilities that they were included in the sample.

Purposive sampling is when sampling locations are deliberately chosen. This may be because they exhibit certain properties, because they are considered typical of a particular type of soil or land use, or because they are on secure sites owned by research institutes. In the case of very small sample sizes purposive sampling may be advantageous because there is less variability in the possible estimates that may be obtained. However, schemes that use purposive sampling are not supported by statistical theory, open to accusations of selection bias and hence are unsuitable for inclusion in the surveillance element of a UK monitoring scheme.

The way to avoid bias is by random sampling. Completely random sampling (Figure 5.1a) suffers from the disadvantage that sampling sites tend to be clustered in certain regions, while other regions are poorly represented. This problem can be avoided by stratified random sampling (Figure 5.1b) or by systematic (grid-based) sampling (Figure 5.1c).

Stratified random sampling aims to place similar sites in the same stratum so that there is less variability within a stratum than between strata. Stratification may be on the basis of variables such as geographical region, soil type or land cover type. The optimal number of sites that should be sampled from each stratum depends both on the size of the stratum and the within-stratum variation of the key variable to be measured. Grid-based sampling ensures even coverage of an area and may lead to potentially greater efficiency. Strictly, systematic sampling has the disadvantage that the sample variance can not be estimated properly. However, treating a grid-based sample as though it were a random sample will tend to over-estimate the true sample variance, so confidence intervals will tend to be wider than necessary and so will be safe to use but somewhat inefficient.

Figure 5.1 Examples of (a) random (b) stratified random and (c) systematic sampling



Practical problems arise in sampling when the selected sites can not be measured (e.g. due to the presence of roads, buildings or water bodies). This is a particular problem if judgement is then used to select an alternative site. Even if there are objective protocols that specify moving a certain distance in a particular direction, this might lead to over-representation of roadside verges and river banks if the moves are too small. Similar problems may arise if a scheme starts with a grid-based system but moves the sampling locations if the land is not of the required type, such as woodland.

Another difficulty arises because each sampling episode usually lasts several months or even several years. If, as a result, sites in one geographical region or under one type of land use are sampled at approximately the same time, whilst those located in another region or under a different land use are sampled at a different time, then apparent variation in space may actually be due in part to variation over time. There may also be an interaction between the timing of sampling and management practice or climate.

5.2 Monitoring

Monitoring involves sampling on more than one occasion in order to detect changes. All of the issues that arise in sampling need to be considered as well as some additional ones.

The most efficient way to monitor is to use paired samples taken from the same location, although destructive sampling obviously means that the location can never be exactly identical. Also relocation of a sampling site after an interval of years can be difficult. These problems can be reduced by taking multiple samples at a site (perhaps at intersections of a small scale (metre) grid about the location) at both the original sampling and the repeat sampling to allow for local (i.e. within site) variation. Use of independent sampling locations (i.e. different locations at different times) is inefficient because it confuses variation in time with variation in space.

Efficient monitoring would have potential sampling locations allocated to strata on the basis of expected change: strata should consist of locations with similar expected changes. Since changes in land use are likely to be associated with relatively rapid changes in soil characteristics and function, it is important they are not excluded by design from a monitoring scheme. Sample size calculations should ideally be based on the variability of change, although for schemes where re-sampling has not yet taken place, information about this may not be available. In these situations it is important to remember that information about spatial variability from a single date may not provide a good indication of variability over time at fixed locations.

One difficulty that arises in monitoring is that sampling locations may become progressively atypical of the population being monitored. This might happen if a characteristic that is used to define the population or strata, such as land use changes over time, or of feedback form the measurements taken affects land management decisions in some way. A possible solution to this problem is to use a rotating panel design in which on each sampling occasion some of the original sampling locations are retained and others are replaced. This type of design provides a balance between extensive population coverage (for status) and repeat visits to the same site (for trend). Another solution would be systematic sample that is resampled at all locations.

Combining monitoring schemes with different stratification would need to involve calculating joint inclusion probabilities for the combined set of sampling locations. Provided the initial sampling selection processes are well understood, then this may be reasonably straightforward. There may be the problem that some combinations of strata that exist in the population are not represented in the set of sampling sites used by either scheme. Just as the strata used in an individual scheme may change over time, so the relationships between the strata used in the different schemes are also likely to change and this may need to be allowed for.

The greatest difficulties in combining monitoring schemes are likely to be due to the lack of consistency in the sample taken (depth/horizon), sampling procedures, analytical methods and in the timing of sampling. Use of multiple techniques and seasonalities at a range of locations would allow calibration equations to be estimated, but in their use it should be remembered that these equations are estimated rather than known and variation about any modelled relationship will need to be allowed for. Use of historical data from individual sampling schemes in which spatial blocks have been sampled in particular years to provide formal estimates of trends is more of a problem. Conversion of estimated changes to annual rates of change is a sensible approach, but formal combination of such data is dependent on an assumption of a constant rate of change.

It is important also to remember that the objective of a monitoring is to measure change. Interpreting that change may require extensive additional information. For example, changes of policy interest (such as the that for soil carbon recently reported in Nature; Bellamy et al, 2005) may be the result of the dynamic nature of soils (through processes such as erosion, soil-building, changes in soil density, transport of elements downwards beyond the measured part of the soil column) as well as through emissions to the atmosphere. Although some of that information may be available from existing process studies, it should not be taken for granted and the adequacy and security of such studies should be considered along with the design of the monitoring scheme.

6. SWOT ANALYSIS OF CURRENT SCHEMES

The strengths and weaknesses of current schemes were assessed with respect to how closely they match the requirements for UK level reporting either solely or as a component of a UK scheme with reporting at devolved administration level and/or for supplying contextual information/explaining understanding change (Table 6.1). The outcomes from the SWOT analyses were summarised in a paragraph for all schemes and used to allocate each scheme to one or more of three categories (A, B and / or C). The categories were defined as follows:

A. Has scope to be expanded or included as part of UK level soil monitoring scheme with reporting at devolved administration level

B. Useful for supplying contextual information/explaining understanding change in UK soil surveillance scheme with reporting at devolved administration level

C. Deliver for their purpose but not useful for UK monitoring scheme (e.g. no UK-SIC indicators measured)

It was acknowledged that some schemes deliver for their purpose but are not useful for a UK monitoring scheme (e.g. no UK-SIC indicators measured). Opportunities for adaptation or combining with other schemes to increase their potential value for supplying data or contextual information for a UK monitoring scheme were also assessed. Possible threats to the schemes were also identified.

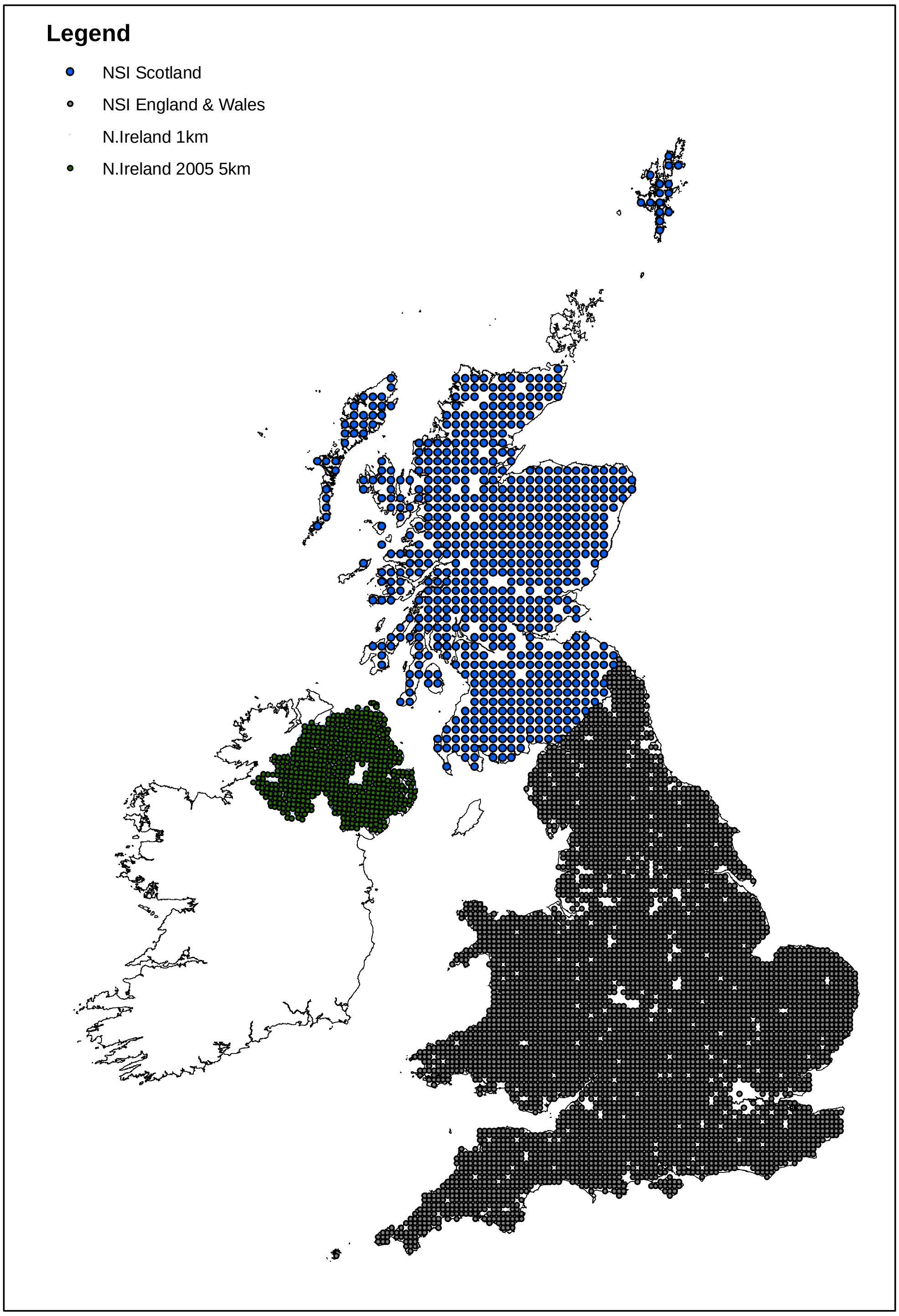
Location of sampling points within some current schemes in 'A' and 'B' categories are shown for illustrative purposes below (Figure 6.1 and 6.2). In designing any future UK scheme, power analyses would be required of current schemes where repeat samples are available to test number of samples required to detect a specified probability of detecting a specified change at a pre-determined significance level. An example from this type of analysis currently underway for Countryside Survey 2007 is shown in Table 6.2 (i.e. there is a 25% probability of detecting a 5% change in soil organic matter (LOI) at the 5% significance level if 120 1km squares were sampled within which there are 5 samples taken (highlighted in red)).

Table 6.1 Classification of current soil monitoring schemes into categories describing level of deployment. Allocation of current soil monitoring schemes into three categories.

Category		
A	B	C
Has scope to be expanded or included as part of UK level soil monitoring scheme with reporting at devolved administration level [1]	**Useful for supplying contextual information/explaining understanding change in UK soil surveillance scheme with reporting at devolved administration level**	**Deliver for their purpose but not useful for UK monitoring scheme (e.g. no SIC measured)**
	ITE/NCC 'Bunce 1971' woodland survey	
Countryside Survey		
Representative Soil Sampling Scheme		
	Rothamsted Classical and other Long-Term Experiments	
National Soil Inventory		
		Soil structural conditions in England & Wales
AFBI 5K PITS 1995		
AFBI 5K 2005		
AFBI 1K 1995		
	AFBI RSSS	
	TELLUS	
National Soil Inventory Scotland + NipAqua		
	Representative Soil Profiles of Scotland	
	Scottish soil map unit transect study	
	Trends in pollution of Scottish Soils	
	Grid Surveys in Scotland	
	Geochemical Baseline Survey of the Environment	
	Geochemical Survey of Urban Environments	
		FOREGS Geochemical Atlas
	Environmental Change Network - soil	
	Environmental Change Network - soil solution chemistry	
	BIOSOIL	
	Level I Forest Conditions survey	
	Level II Intensive Monitoring of Forest Ecosystems	
	Level II Intensive Monitoring of Forest Ecosystems- soil solution	
	Long Term Sludge Experiments	
	Effects of organic carbon inputs on soil quality	
		NSRI Representative soil profiles
	UK Soil and Herbage Survey	

[1] See text in Section 8 as to final recommendation on options for integration or expansion.

Figure 6.1 Location of current sampling locations of NSIs[1]



[1]For NSI Scotland 10 km grid intersections sample points are shown. All 10 km points were sampled, but only a subset of 5 km intersections were sampled

Figure 6.2 Sampling locations in BIOSOIL, Bunce Woodland Survey and CS

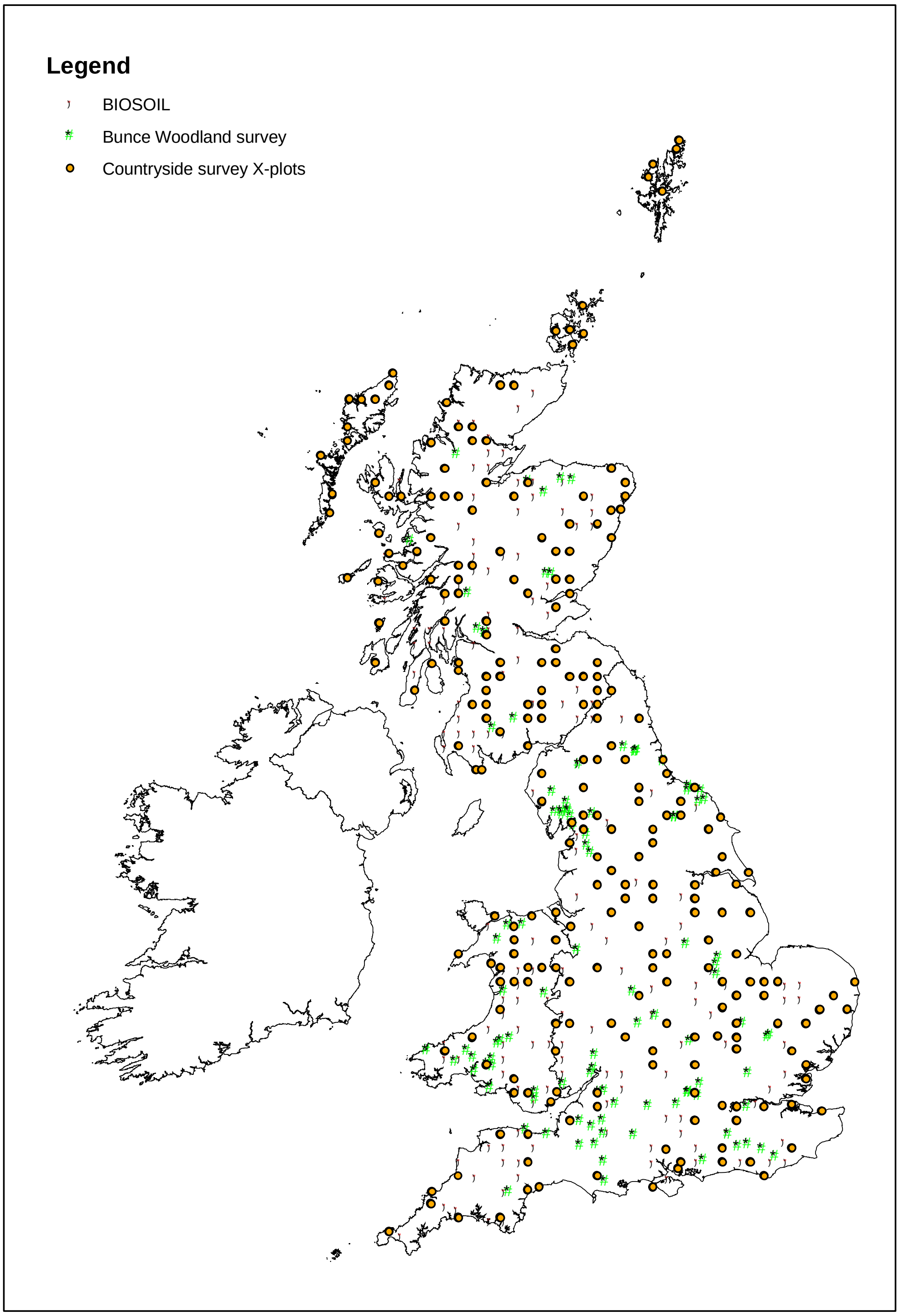


Table 6.2 Power to detect various degrees of change in soil organic matter with various sample sizes in Wales.

		Percentage change in LOI			
Sample size	**Significance**	**5%**	**10%**	**20%**	**30%**
20	**1%**	3.6	10.0	40.6	79.0
(1978/2000)	**5%**	7.5	18.0	55.1	88.0
	10%	13.1	27.4	67.2	93.2
65	**1%**	8.3	32.9	92.5	100.0
(current)	**5%**	15.4	46.9	96.5	100.0
	10%	24.1	59.4	98.3	100.0
90	**1%**	11.2	45.6	98.2	100.0
	5%	19.7	60.1	99.3	100.0
	10%	29.6	71.6	99.7	100.0
120	**1%**	14.8	59.2	99.7	100.0
(proposed CS2007)	**5%**	**24.8**	72.5	99.9	100.0
	10%	35.7	82.0	100.0	100.0

7. GENERIC ISSUES IDENTIFIED FOR CURRENT SOIL MONITORING SCHEMES

An informal analysis of the schemes identified the following generic problems inherent in many or all schemes:

i. the absence of some UK-SIC indicators from most schemes namely soil moisture at 1m, soil aggregation and potentially mineralisable-N
ii. lack of consistency in samples taken and sampling procedure;
iii. lack of consistency in methods of analysis;
iv. limited number of soil physical measurements;
v. purposive statistical design in many schemes which could result in bias if scheme was used for a purpose other than that intended in the original scheme (see Section 5).

8. OPPORTUNITIES AND LIMITATIONS TO INTEGRATING AND / OR ADAPTING CURRENT SCHEMES

A two day workshop attended by members of the research consortium identified the following issues concerning opportunities and limitations for integrating and/or combining current soil monitoring schemes to deliver a UK soil monitoring scheme. This is again summarised using the SWOT approach:

8.1 Strengths

- The UK is rich in soils data at a range of relevant spatial and temporal scales, which, if integrated well, could support a UK-scale soil monitoring scheme.
- There are sufficient non-purposive schemes in existence to provide at least some information on the status and change in many UK-SIC indicators, in particular the current MDS indicators.

8.2 Weaknesses

- Schemes which are designed to measure change within single land cover / land use types will not measure the effects of changes in land use and so will not provide full information about changes in the properties and functions of UK soils.
- Purposive sampling has no objective or statistical basis, so schemes involving purposive sampling can not be relied upon to provide an unbiased account of the stock and changes in UK soils.
- The major constraint for harmonising data between the ‘A’ schemes is the lack of consistency between schemes in soil depth/horizon sample and sampling procedures, analytical procedures and periodicity of sampling (variable baseline, seasonality).
- Even if scheme harmonisation was achieved, there would remain no coverage for some UK-SIC indicators.
- There has been no consideration of the practicalities or regulatory requirements of current national-scale soil monitoring schemes. These will need to be addressed in the design of any new scheme. This has particular resonance for expanding or integrating with current schemes since data within these schemes may not be suitable or available for regulatory purposes.
- Urban areas are poorly covered

8.3 Opportunities

- Any integration/harmonisation of current schemes with a new UK scheme would require: (i) schemes in question to move towards a standard set by UKAS accreditation (when available) for laboratory analyses, which would improve the capacity to use these data for a wider range of purposes, and (ii) work to be carried out to quantify the relationship between the data produced by the methodologies used in current schemes with UK-SIC agreed methodologies.

- Calibration equations could be estimated to overcome some of the inconsistencies in previous protocols when bringing together data which lack consistency, but in their use uncertainty in the relationships will need to be allowed for.
- One option is the expansion of one of the statistically robust, non-purposive "A" schemes to cover all of the UK and all UK-SIC indicators. This would capitalise on current data and contextual information in that existing scheme. Schemes which fall into the 'A' category are: AFBI schemes, CS, NSIs, and RSSS. It should be noted this could have significant implications for the continuity of the current remit of the scheme selected and additional level of contextual information might be required depending on the scheme selected.
- Alternatively, initial sampling locations could be taken from more than one such scheme. This would guarantee estimation of change for a wider set of variables in the transition period to a new UK scheme.
- Current schemes would be able to report on many UK-SIC indicators (state and change) in the transition period whilst a UK scheme is established and there are strengths as already noted in the use of a variety of methodologies between schemes.
- Intelligent use and integration of existing and future data from current schemes could provide the capacity to investigate the causes of change identified from a more generic UK-scale soil monitoring scheme, including the relative importance of different environmental pressures and drivers at different spatial and temporal scales
- The research consortium was keen to highlight the value of information derived from several schemes using different methods providing a body of evidence which can either challenge or confirm change reported from any one individual or newly formed UK scheme.

8.4 Threats

- Adapting current schemes to fulfil all or part of the requirements of a UK monitoring scheme could compromise the ability of individual schemes to deliver their current purpose
- The research consortium were also keen to highlight the potential weakness of relying on one scheme as standard methods for analytes are often a compromise not suited to all environments or requirements.

9. CONCLUSIONS

1. The research consortium concluded that it is not possible to integrate and/or combine existing schemes to deliver the full requirements of a UK soil monitoring scheme due to problems identified with differences in methodology and timing of sampling.

2. Current schemes can provide a framework to establish a new scheme and information on status and change of UK-SIC indicators during a transition period. They could also provide contextual information to help interpret and understand change whilst running concurrently with a new UK scheme.

3. A second option is to select one of the existing schemes operating at country or GB level which has the recommended statistical design and to expand it to include all UK-SIC indicators plus the required contextual information to allow country-level and UK level reporting.

4. Whatever approach is taken, the exact purpose of, and required outcomes, of a UK-scale soil monitoring scheme will need to be carefully specified to ensure that the design meets all expectations/needs.

5. The research consortium recommends that any new UK scheme should contain two distinct elements.
   a. Firstly, a monitoring element with broad spatial coverage which needs to be designed to allow changes of specified sizes in specific regions to be detected with known power. This element would have to be statistically robust and be capable of detecting changes as a result of changing land use / cover patterns. Sampling locations could either be grid-based or random but in either case a known sampling framework would be required. One option in any new UK monitoring scheme might be to adopt a rotating panel design in which sampling locations are dropped after a period of time to ensure that the population for which inferences are required is fully represented.
   b. Secondly, contextual information is required to allow changes measured by the surveillance element to be understood and interpreted. Without this second element, the causes and hence policy implications of changes detected by the surveillance element would be open to challenge.

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Appendix 1 Acronyms and abbreviations of schemes

ITE/NCC 'Bunce 1971' woodland survey	NCC woods
Countryside survey	CS
Representative Soil Sampling Scheme	RSSS
Rothamsted Classical and other Long-Term Experiments	RothRes LTEs
National Soil Inventory	NSI
Soil structural conditions in England & Wales	Soil Struct.
AFBI 5K PITS 1995	AFBI 5K 1995
AFBI 5K 2005	AFBI 5K 2005
AFBI 1K 1995	AFBI 1K 1995
AFBI RSSS	RSSS(NI)
GSNI TELLUS 2004-06 (= BGS's G-BASE scheme in the rest of the UK).	TELLUS
National Soil Inventory of Scotland	NSIS +NipAqua
Representative Soil Profiles of Scotland	RSPS
Soil map unit transect study	SSMUTS
Trends in pollution of Scottish Soils	TIPSS
Grid Surveys in Scotland	Grids Scot
Geochemical Baseline Survey of the Environment	G-BASE
Geochemical Survey of Urban Environments	GSUE
Forum of European Geological Surveys European Geochemical Atlas	FOREGS
Environmental Change Network - soil solution chemistry	ECN
Environmental Change Network - soil	ECN
BioSoil	BioSoil
Level I Forest Conditions survey	Level I
Level II Intensive Monitoring of Forest Ecosystems	Level II
Level II Intensive Monitoring of Forest Ecosystems - soil solution	Level II
Effects of sewage sludge applications to agricultural soils on soil microbial activity and the implications for agricultural productivity and long term soil fertility.	Sludge
Effects of organic carbon inputs on soil quality	SOIL-QC
NSRI representative soil profiles	NSRI-RSP
UK Soil and Herbage Survey	EA-Soils

Appendix 2 Definitions of criteria codes used to assess soil monitoring schemes presented in the catalogue.

	Parameter	Codes
Scheme Details	**Name**	Not coded
	Abbreviated name	Not coded
	Overall purpose	Not coded
	Current contact	Not coded
	Organisational contact	Not coded
	Project status	1 = closed 2 = closed pending future funding 3 = Still open/on-going
	Main outputs	Not coded
Sampling framework - Selection of primary sampling points	**Spatial area considered for sampling**	1 = single country 2 = two countries 3 = three countries 4 = UK 5 = Europe
	What geographical, habitat or other criteria have been used to define the target sampling	1 = urban areas only 2 = non-urban areas only 3 = urban and non-urban areas
		1 = farms/cultivated land 2 = woodland 3 = soil 4 = representative intensive site(s) 5= not targeted
	Stratification	0 = none 1 = ITE land class 2 = soil landscape 3 = land use 4 = soil type
	Number of primary sampling points & allocation to strata	Number of primary sites
	Describe any randomisation scheme used or basis of systematic sampling	0 = no randomisation 1 = randomised on fixed grid 2 = randomised by other criteria 3 = purposively located
	Reasons for excluding or moving primary sampling points	0 = protocols do not allow points to be moved 1 = protocols allow points to be moved 2 = protocols do allow points to be deleted

Sampling framework - Selection of secondary sample points (if present)	**How were secondary sampling points located within each primary unit?**	0 = no secondary sampling 1 = randomised on fixed grid 2 = stratified random 3 = purposively located 4 = no randomisation
	Please give the numbers of secondary points per primary point, and allocation to substrata	Number of secondary sites
	Describe any randomisation scheme used or basis of systematic sampling	0 = no randomisation 1 = randomised on fixed grid 2 = randomised by other criteria 3 = purposive
	Reasons for excluding or moving secondary sampling points	0 = protocols do not allow points to be moved 1 = protocols do allow points to be moved 2 = protocols do allow points to be deleted
Sampling framework - Selection of tertiary sample points	**How are tertiary sampling points located within each secondary unit?**	0 = no tertiary sampling 1 = randomised on fixed grid 2 = stratified random 3 = purposively located 4 = no randomisation
	Numbers of tertiary points per secondary point	Number of tertiary sites
	Description of any randomisation scheme used or basis of systematic sampling	0 = no randomisation 1 = randomised on fixed grid 2 = randomised by other criteria
	Reasons for excluding or moving tertiary sampling points, including response to difficulties	0 = protocols do not allow points to be moved 1 = protocols do allow points to be moved 2 = protocols do allow points to be deleted
Level of soil characterisation	**Please state level of soil characterisation recognised in the sampling scheme**	0 = not identified 1 = major soil group 2 = sub-group 3 = series 4 = soil association or soil map unit
Timing of sampling	**Start and end date of first round of sampling**	Start date
	How many times has the cycle of measurements been repeated?	Number of cycles
	What is the time interval between measurement episodes?	Interval between cycles in years

	How long does each sampling episode take and when is sampling undertaken?	Time taken in months to complete whole cycle
	Describe any relationships between timing of sampling and confounding factors	0 = No seasonal definition for re-sampling 1 = Seasonally defined re-sampling
Estimation of change	**If re-sampling has already taken place, please describe procedure used**	1 = all sites re-sampled 2 = statistical subset re-sampled
	Have sampling strata / locations changed over time?	0 = no changes, same site each re-sampling 1 = site changed (same numbers) each re-sampling 2 = sites added or deleted according to selection criteria
	Has the sampling scheme changed for each cycle?	0 = same scheme 1 = revised scheme
	Specify how sample points are relocated between measurements	1 = located by NGR 2 = located by GPS 3 = located by fixed marker 4 = other
	Specify reasons for excluding or moving sampling points	0 = protocols do not allow points to be moved 1 = protocols do allow points to be moved 2 = protocols do allow points to be deleted
	Are estimates of precision of estimates of change available?	0 = no 1 = yes
Supporting information	**List all contextual parameters measured or recorded <u>at the site</u> at the same time as soil sampling**	Number of parameters recorded
	List the drivers of change recorded on visit dates and at intermediate times	Number of parameters recorded
	At what scale are the drivers of change recorded?	0 = not recorded 1 = site 2 = field 3 = landscape unit 4 = parish 5 = wider area
	Describe any concurrent process studies which aim to elucidate causes of change / processes involved	0 = not recorded 1 = recorded
	What are the physical dimensions of the sample?	Weight - field wet – kg

Sample collection & sample handling	**What is the vertical sampling interval and what method was used?**	1 = sampling by depth by auger 2 = sampling by horizon by auger 3 = sampling by depth by pit 4 = sampling by horizon by pit
	Where is sampling depth measured from?	0 = excluding litter 1 = including litter
	Are the samples kept separate or are they bulked at any stage?	0 = not bulked 1 = bulked by depth 2 = bulked by horizon 3 = no samples
	How is site location information recorded?	1 = NGR 2 = permanent marker 3 = by sectioning 4 = GPS
	Have any of the soil sampling protocols change between survey cycles?	0 = no change to protocols 1 = protocols changed
Soil analysis	**Please list soil parameters measured**	Number of parameters
	Briefly specify sample preparation for each analyte / parameter	Not coded
	Briefly describe methods of measurement for each analyte / parameter	Not coded
	Please provide brief details on data quality	0 = no formal QA 1 = QA by internal scheme 2 = QA by external scheme
	Have soil analysis protocols changed between survey cycles?	0 = no change to protocols 1 = protocols changed
Data and sample storage	**Data or IP holder**	Not coded
	Freedom of data access	0 = no access 1 = outright purchase 2 = licence 3 = free 4 = variable according to need
	Level of data access	1 = raw data 2 = derived data only 3 = raw and derived data
	Data format	1 = incomplete records 2 = obsolete digital format 3 = paper record only 4 = readily transferable to commonly used digital format at low cost 6 = held in commonly used digital format

	How complete are the data records?	0 = no gaps in data; 1 = gaps in data resulting from problems not identified in text 2 = gaps in data and cause identified in text
	How many data items are stored per determinand for each sample?	0 = single data values for each determinand 1 = multiple data values for each determinand 2 = varies
	How exhaustive are the data records?	0 = database does not include raw data 1 = database includes raw data 2 = limited data available
	Please specify method of sample archiving / what material is archived	1 = air dried 2 = sieved < 2mm 3 = dried and sieved 4 = frozen
	How complete is the stored sample archive?	0 = no gaps sample archive 1 = gaps in sample archive resulting from problems not identified in text 2 = gaps in sample archive and cause identified in text
Any further information	**Please add any further information or comments as free text**	Not coded