The function of soil biodiversity as indicators of soil quality: Insights from the UK Defra SQID project

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Abstract
This presentation outlines the final results from the UK Defra SQID project which identified and piloted a suite of biological indicators of soil quality for deployment in national-scale soil monitoring programmes to meet a range of UK policy objectives. The indicators were selected to provide information on the soil biological processes which underpin soil function and therefore support ecosystem services. A semi-quantitative framework was used to systematically capture the wealth of information in the literature and from expert knowledge on potential indicators of soil quality with a total of 183 indicators assessed. Six soil biological methods have now been piloted in the UK using two complementary field approaches. These six reflect the genotypic, phenotypic and functional characteristics of soil biodiversity. Here we review the results from the two field approaches, the first to assess the temporal sensitivity of biological indicators to key environmental pressures across a 12 month window and the second to asses the ability of biological indicators to discriminate between different habitats. We discuss the relative performance of the indicators and how these were prioritised for national-scale soil monitoring and finally, how this process has revealed new insights into the distribution and characteristics of soil biological properties within UK soils and habitats.

Key Words
Soil quality, biological indicators, sensitivity, discrimination.

Introduction
Soil organisms are important to the maintenance of many ecosystem processes and properties which underpin vital soil functions (Bardgett *et al.* 2005) and it has been suggested that the diversity and behaviour of the soil biological community have great potential in detecting changes to soils brought about by various pressures such as climate change or pollution (Fließbach *et al.* 2007). Indeed a UK Royal Commission on Environmental Pollution concluded that biological indicators should be included in any future monitoring of soil quality (RCEP 1995). However, although many soil biological parameters are being proposed as indicators of soil quality, few have been tested for use in national monitoring programmes which operate over large spatial and temporal scales (Black *et al.* 2008). We have recently completed a project funded by the UK Department of Environment, Food and Rural Affairs to trial a limited range of soil biological parameters to assess their robustness for use in national scale soil monitoring programme. Here we present results from our two field comparisons of the following biological parameters; N, C, P & S enzyme responses using a multi-enzyme fluorometric assay; carbon substrate utilisation using a multiple substrate induced respiration assay (Microresp™); microbial community structure from phospholipids fatty acids and using MTRFLP on DNA extracts; and finally both microarthropod and nematode community structures from morphological identification. These indicators were prioritised through a robust assessment process and show high relevance and applicability to large-scale monitoring of soils (Ritz *et al.* 2009). The biological indicators under investigation also have specific relevance to the maintenance of soil health, via the delivery of ecological processes, and are highly relevant to the soil functions of food and fibre production, environmental interactions, and ecological habitats and biodiversity.

Methods
The project involved four aspects; logistical issues such as reproducibility of results from standard operating procedures; the sensitivity of the each biological indicator to three important environmental pressures (atmospheric pollution, land restoration and heavy metals); the ability of the indicators to differentiate between different habitats and, ultimately, the relative performance of the range of genotypic, phenotypic and functional biological indicators of soil quality. The primary purpose was to rigorously test these indicators under relevant field conditions and re-evaluate their suitability for national soil monitoring.
In the first trial, the sensitivity of each parameter was assessed against its temporal variability over 12

months within three field experiments, each representing a distinct pressure / driver (atmospheric N deposition, applications of metals through sewage sludge and restoration of land). In the second trial, the parameters were tested to see if they could discriminate between habitats. The approaches to the field trials are outlined in the following.

A To test the biological indicators for their sensitivity to distinct environmental pressures
The aim of this objective was to evaluate the potential indicators in the specific context of distinct environment pressures, against the associated background of temporal and spatial heterogeneity. To this end, soils derived from well- established and replicated field experiments were utilised, where pressures have been defined and controlled, with appropriate replication. The three sites provide contrasting pressures that relate to the key soil functions (*viz.* food/fibre, environmental interactions, habitat/biodiversity). These are sewage sludge applications to agricultural land, simulated atmospheric nitrogen deposition on upland grassland habitats and restoration of open-cast mine sites. To assess sensitivity of the individual indicators against their temporal and spatial variability, soil samples were taken bi-monthly throughout a one-year period. Each member of the consortium was responsible for field sampling at their specified site and the distribution of soil samples to the relevant partners for laboratory analyses. Biological indictor responsiveness was assessed from all occasions and subsequent data analysis comprised a variety of statistical techniques, including multivariate analyses.

i) Site 1: Sewage sludge trial.
The re-cycling of wastewater sludge to land is a common practise on many grassland and arable soils and can result in considerable ecological and agricultural benefits. However, when sludge that is high in heavy metals is used the build up of potentially toxic elements can reduced the size and activity of the microbial biomass and reduce the numbers of effective N-fixing Rhizobium. It therefore makes a suitable test case to evaluate both the benefits and potential damage that such re-cycling practises might put on soil. The Hartwood field site (Scotland) was selected from UK Sewage Sludge Network. An advantage was the long term datasets for chemical and other microbiological data for comparison. The sampling design comprised four treatments by three field replicates on six occasions.

ii) Site 2: Atmospheric nitrogen deposition in an upland grassland trial.
There is now evidence of widespread changes in plant diversity in the UK and eutrophication is likely to be one of the main reasons for these changes, with atmospheric deposition of nitrogen playing a significant role. As well as affecting individual plant species, and potentially soil biodiversity, the deposition of nitrogen could pose a threat to conservation-status habitats and the already acidified freshwater ecosystems in upland areas of the UK. Critical load exceedance for nitrogen makes water quality at risk from increased nitrogen leaching from soils under many habitats. The ADAS Pwlllpeiran upland grassland site (Wales) was selected from several field experiments that address both the addition of nitrogen at varying concentrations are available via the Defra Terrestrial Umbrella network. This site had experience 7 years of long-term N additions. Again an advantage was the long term datasets for vegetation and soil chemical properties available. The sampling design comprised four treatments by three field replicates on six occasions.

iii) Site 3: Restoration gradient.
From available land restoration programmes, soils were taken from the Sutton Courtney mine reclamation site in S. England. This site has been subject to opencast coal mining operations and subsequently restoration over recent decades. There was a restoration gradient from undisturbed benchmark sites (e.g. woodland) and restoration counterparts at a variety of ages since re-instatement. The sampling design comprised twelve samples on a transect, aligned to the restoration gradient, taken on six occasions.

B To test the biological indicators for their ability to discriminate between a diverse range of habitats.
The aim was evaluate the discriminatory power of the potential indicators with respect to the typical range of habitats in the UK. The nature of the discrimination trial was not to specifically target extremes but rather to test the robustness of these indicators under a wide range of conditions likely to be encountered in a large scale monitoring exercise. Nine habitats were selected to include soils at the extremes of certain key properties e.g. acid to calcareous soils; moorland to arable soils (Figure 1).
Soil samples (0 – 15 cm depth; 10 samples per habitat) were obtained from the field survey of Countryside Survey 2007. The value of linking to CS2007 was the opportunity to access the wide-range of associated environmental data, much of it obtained from co-located sampling plots. These data include; plant species

richness, broad habitat type, Ellenberg plant community scores (indicative of environmental gradients such as fertility, shade, etc), soil type/pH/carbon content etc, geological parent material, slope, altitude, Land Cover (from LCM2000). Data were analysed using a variety of statistical techniques contingent on the type of data. This will include mixed-model ANOVA, principal component analysis, canonical and other correspondence analyses.

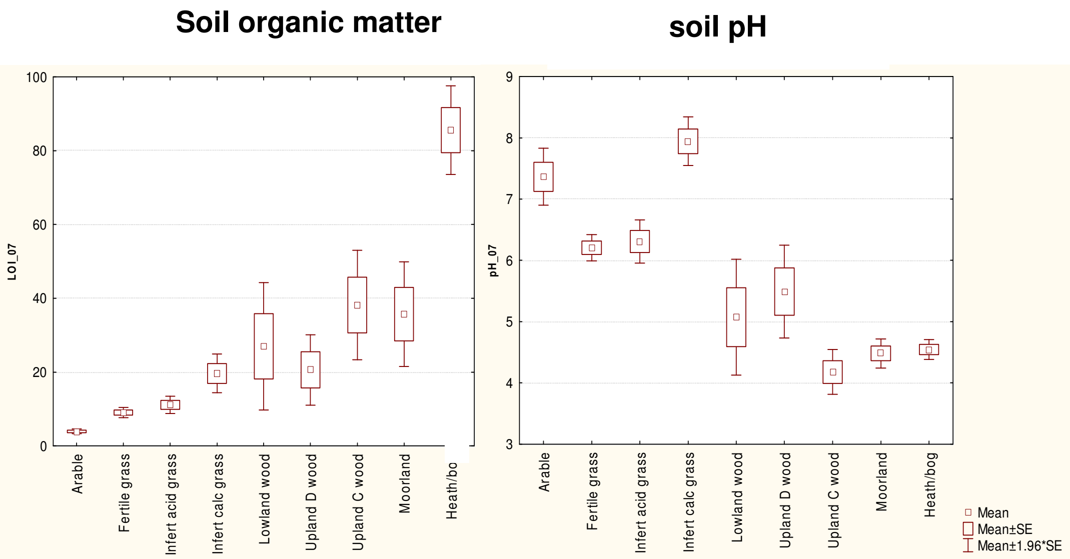

Figure 1. Soil organic matter and soil pH characteristics of the nine habitats sampled during Countryside Survey 2007 for the Defra SQID project (n = 100).

Conclusion

The results from the sensitivity and discrimination trial produced a wealth of statistically significant responses from direct, derived and multivariate measures of soil biological properties to the three environmental pressures and nine habitat types and clearly demonstrate the potential of different methods for application in monitoring. Using consistent approaches to the statistical analyses of all the biological indicators, and their associated measures, we have been able to directly compare the relative performance of genotypic, phenotypic and functional biological indicators and prioritise indicators for national-scale soil monitoring. The prioritisation also considers logistical issues such as reproducibility of results using standard operating procedures. In parallel, we have devised a novel approach that integrates the wealth of information that can be derived from biological indicators of soil quality using genotypic, phenotypic and functional characteristics. This trait-based approach is providing new insights into the distinct characteristics of soil biodiversity under different habitats and the potential consequences of environmental change on soil biodiversity.

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