

Long Term Monitoring Network: monitoring soils 2011 to 2016

Climate change and air pollution are expected to cause substantial changes in the natural environment. Natural England has developed a Long Term Monitoring Network (LTMN) of 37 core sites on a range of target habitats across England to help us understand what these changes might be and how we might be able to mitigate against any damaging effects. This note provides information on the LTMN baseline soils monitoring that started in 2011 and was completed in 2016. Links to other LTMN information can be seen in the *Further information* section at the end of this note.



A podzolic gley soil profile ready for description (Chobham Common, 2014)

Why are we monitoring soils?

Soils are a structured mixture of mineral material, air, water, organic matter and organisms. They underpin, and are part of, all terrestrial ecosystems. Ecosystem services delivered by soils and the organisms that inhabit them are hugely important for life on land, and include the cycling, storage and release of carbon, nutrients and water (UK National Ecosystem Assessment, 2011). Soils mediate the flow of water through landscapes and provide a growing medium for the crops that feed us.

Soil is also an astonishingly diverse and fascinating biodiversity phenomenon. Approximately one quarter of all animal species are thought to be soil-dwellers (Decaëns and others, 2006) as are most plants. Many other animals species rely on the soil and its functions as much as we do. The microbial diversity of soil is vast and its genetic and chemical diversity provides numerous medicines, pesticides and industrial biochemicals.

Natural England's Long Term Monitoring Network: monitoring soils 2011 to 2016

Monitoring our soils can help give us insight into how soils work, how soil characteristics are related to each other and how soil conditions differ between different habitats. It should help us identify inexpensive simple soil measurements which can be used as reliable indicators of soil conditions, to replace more expensive complex measurements.

Future monitoring should help us to understand whether changes in soil properties can be related to changes in land management, climate and pollutant deposition, and enable us to identify the most sensitive indicators of these changes in the soil. The data will help us to link soil conditions with soil functions, especially where standard monitoring is linked to experimental study at the same sites.



For example, the data could link organic matter quality and nutrient supply with different decomposer communities, or help determine how soil conditions interact with changes in aboveground biodiversity. Ongoing monitoring should also tell us about changes in carbon storage in our soils and peatlands. The monitoring data will also provide an understanding of the range of soil biodiversity in England associated with our most valued conservation habitats, and help us understand whether rare and unusual habitats associated with rare and unusual soil organisms, perhaps providing valuable indicators of past site history.

Ongoing monitoring should help reveal whether our soil biodiversity is declining, or keeping pace with environmental change, and how it may be responding to recent environmental changes, such as reduction of acid deposition. A clearer understanding of soil conditions alongside the LTMN's vegetation data should help us understand the soil conditions required by the plants in our valued habitats, and how these interact with the soil biological community. In short, monitoring of soils is essential to our understanding of the impacts of environmental change on terrestrial ecosystems, and will reflect that part of these systems which delivers our most essential services and functions.

Past efforts to monitor soils have focussed on soil chemistry (eg the representative soil sampling carried out by MAFF) or both chemistry and physical aspects of soil (eg the National Soil inventory, NSRI). More recently soil monitoring has attempted to include elements of soil biology and function as

Natural England's Long Term Monitoring Network: monitoring soils 2011 to 2016

exemplified by the 1998 and 2007 Countryside Surveys (Emmett and others, 2010). However there is no ongoing national monitoring programme for soils, and the LTMN soils monitoring represents one of very few national ongoing efforts to understand how our soils are changing over time.

Soil "health" can be thought of in similar terms as the health of a human being. In order to understand the health of patient, a doctor takes many different measures and observations, and undertakes many different tests before making a diagnosis or recommendation. This approach is also applied to monitoring soil health. A wide range of chemical, physical and biological parameters were included in the monitoring scheme. To ensure our data is both reliable and compatible with past efforts measurements were selected for their reliability and their extensive use in other surveys, and the samples were taken in ways that were designed to be compatible with previous efforts, especially the Countryside Survey 2007, which provides a national context for the data collected. Inevitably, this means that the most recent approaches in soil science are not reflected in the monitoring programme, and it is an ongoing challenge to ensure that the monitoring programme continues to provide information that is useful to future scientists and policymakers.

How we monitor soils

Each year between 9 and 4 sites are selected for fieldwork. The soil monitoring plots are associated with, but offset from, the plots used for LTMN vegetation monitoring which are marked with a yellow ground-level marker. This vegetation data, other site survey data and aerial photos are used to select a shortlist of sampling points that aim to represent a single vegetation type on each site. Five of these sampling points, which often represent a compromise between suitable ground conditions and vegetation, are selected and sampled using the protocol below.

Each sampling point is visited within the period September 15th and October 15th for field assessment and soil sampling. The LTMN vegetation monitoring plot and marker is relocated using a GPS, and the soil plot is established, usually 5.66 m SW of the yellow marker. A 20 m by 20 m sampling plot is laid out using temporary tapes and an additional red permanent marker is placed at its most distant (usually SW) corner. The locations of the sampling plot corners are recorded by GPS, plot photos are taken, and four 2 m by 2 m subplots marked out. In these subplots photos are taken of the vegetation and a quick vegetation survey completed, recording species and percentage cover of species (or other ground cover) with >5% cover are estimated to nearest 5%. These subplots are the same for all baseline plots sampled, and a new set of subplots will be randomly selected for resampling. A soil auger is used to extract, photograph and describe the soil profile to up to 1 m depth (texture, colour and depth of horizons) at one subplot and soil samples are collected for analysis from all other subplots, and bulked together for each sampling plot.

Plastic tubes are cut and driven into the ground to retrieve intact samples for soil mesofauna (4 cm diameter, 8 cm length), nitrogen mineralisation (4cm diameter, 15cm length) and physico-chemical soil properties (5 cm diameter) at 0-15 cm and 15-30 cm depths. A long narrow trowel is used to collect 2 further bulked samples from all four subplots for microbial community and nematode community analysis. On peaty sites a Russian auger is used to collect intact peat samples down the peat profile and peat depth is measured using metal rods for all 4 sub plots.

Natural England's Long Term Monitoring Network: monitoring soils 2011 to 2016

All samples are transferred to cold storage to help slow microbial changes, and are sent to the James Hutton Institute for analysis. This analysis includes moisture content, stone volume, bulk density, loss on ignition (soil organic matter content), pH (in water and CaCl solution), total C and N, extractable cations (Fe, Al, Mg, Mn, K, Ca, Na, H) and mineralisable nitrogen using the method developed for the Countryside Survey (Rowe and others, 2011). Biological measurements included Phospholipid Fatty Acid profiling, to indicate soil microbial biomass and community composition, tRFLP for soil microbial genetic diversity, Tullgren extracts for soil mesofauna (visible animals that can pass through a 2 mm diameter hole) and nematode extracts from 200g of fresh soil using a modified Baermann technique. Samples from year 1 were also analysed for total P and Olsen P, but results were variable due to some low pH soils making these samples less suitable for this analysis. Dried ground samples have been retained for further P analysis. Some efforts have been made to identify the Tullgren extracts using microscopy and by training volunteers, but so far only one site has complete data, while two other sites have partial data available.

All data have been collated into a spreadsheet and the results up to 2015 are now available through open government data licence at [Long-term monitoring network soils data](#).

Results

Only the baseline sampling has been completed so the programme is not yet able to detect changes over time. However, the wide range of different semi-natural habitats sampled provides a broad overview of the nature of soils in England, enabling the identification of important fundamental patterns in the soil parameters measured.

Many soil physical and chemical conditions are clearly correlated with organic matter content (% of dry weight) as measured by loss on ignition. Around 85% of the variability of soil water content could be predicted from organic matter content (Figure 1), despite different weather conditions during the 6 years of baseline surveys.

Natural England's Long Term Monitoring Network: monitoring soils 2011 to 2016

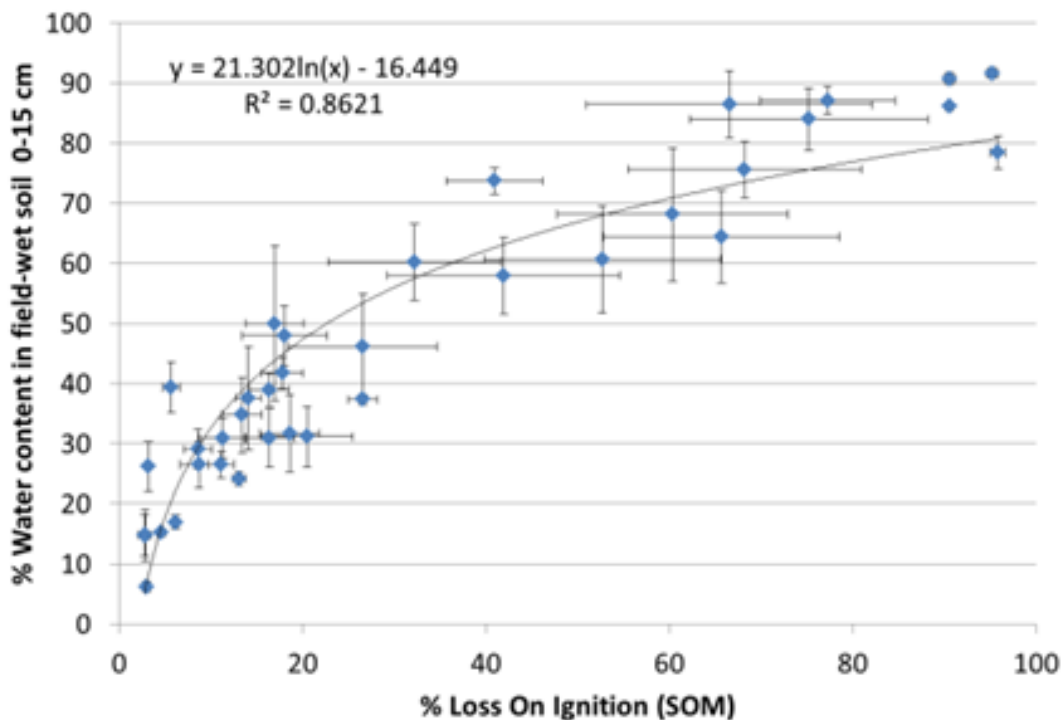


Figure 1: Around 85% of the variability of soil water content could be predicted from organic matter content despite different weather conditions during the 6 years of baseline surveys

The density of both topsoils and subsoils was negatively correlated with organic matter (Figure 2), and cation exchange (the ability of soil to hold onto plant nutrients) increased with increasing organic matter.

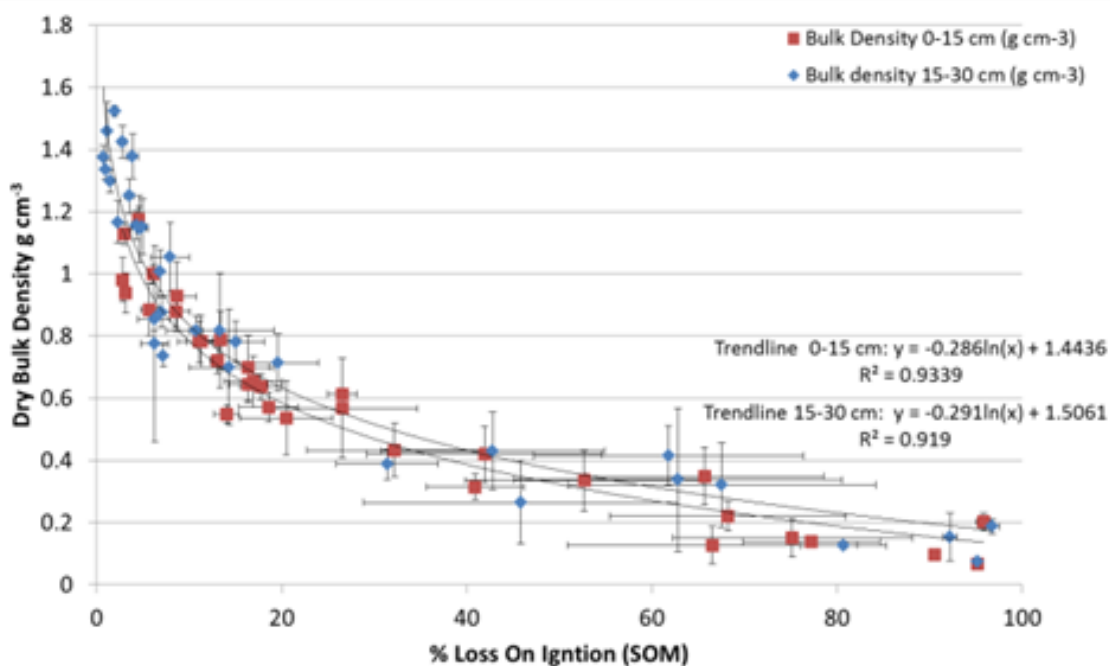


Figure 2: The density of both topsoils and subsoils was negatively correlated with organic matter

Natural England's Long Term Monitoring Network: monitoring soils 2011 to 2016

We've used this data, along with estimates of the density of mineral material and organic matter to show how the volume of different soil constituents varies over the range of organic matter contents (Figure 3). This shows how, as soil organic matter content increases the volume of water increases, until it exceeds the volume of air. It also shows how, as organic matter content increases, the proportion of its volume in the soil doesn't increase so much, due to the retention of this additional water. The soils with the highest organic matter content represent waterlogged peat with almost no volume of air or mineral material.

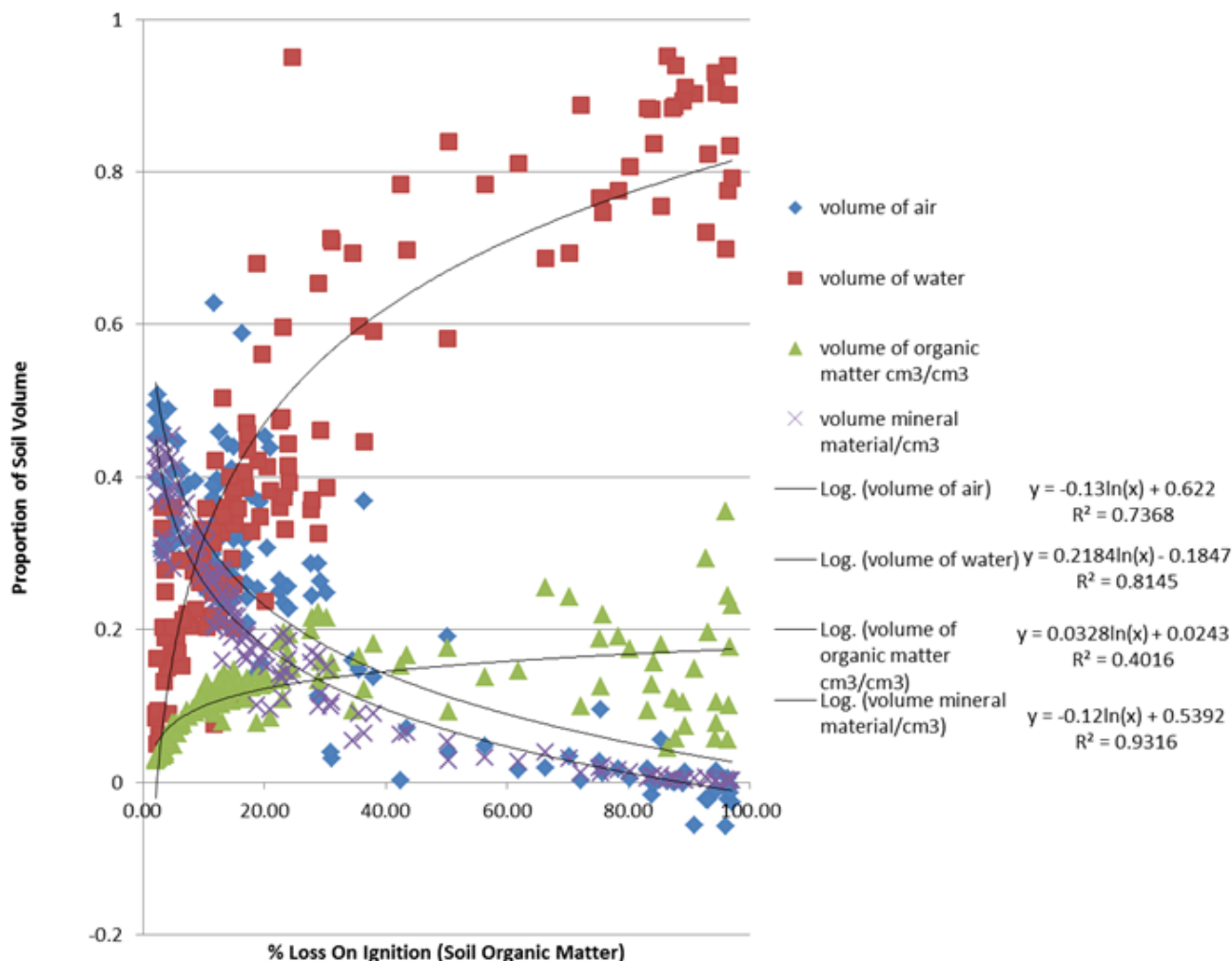


Figure 3: LTMN data on the relationship between the volume of different soil components and the percent content by weight of organic matter

The data reveal that soil biological communities are not only driven by organic matter content, but also by soil chemistry, and pH in particular.

The amount and composition of microbial cell wall constituents (Phospholipid Fatty Acids: PLFAs) is an indicator of the diversity of the microbial community. A multivariate analysis was used to show the similarities and differences between the communities of microbes in each sample plot for all 37 sites (Figure 4).

Natural England's Long Term Monitoring Network: monitoring soils 2011 to 2016

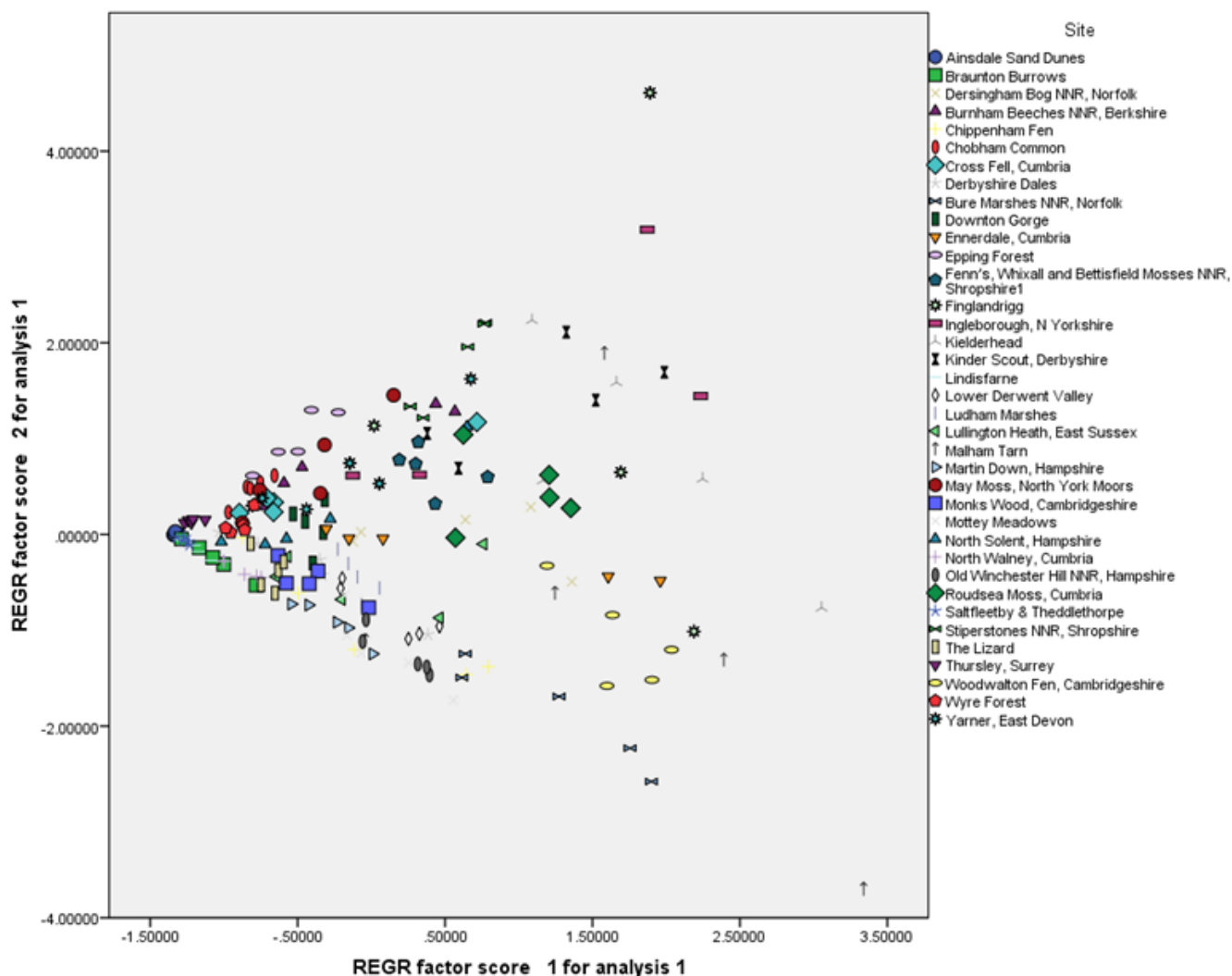


Figure 4. Characteristics of soil microbial communities, as determined by PLFA analysis, showing a scatterplot of scores on two axes which explain 68% of data variance, derived from a principle components (factor) analysis.

Microbial communities are distinctive between many of the sites, although there are some clear areas of overlap. Sites on the left hand side of the graph are have more similar communities, and are generally those with sandy soils with low organic matter content, low water content and high bulk density. Sites on the right of the graph are more variable and generally have peaty soils. The spread of sites from top to bottom of this graph largely reflects their soil pH, with more acidic sites at the top and more calcareous sites at the bottom.

Analysis of PLFAs revealed that the balance of fungi to bacteria in the soil increased with increasing soil carbon:nitrogen ratio, confirming that fungi are more associated with low-nutrient substrates (Figure 5).

Natural England's Long Term Monitoring Network: monitoring soils 2011 to 2016

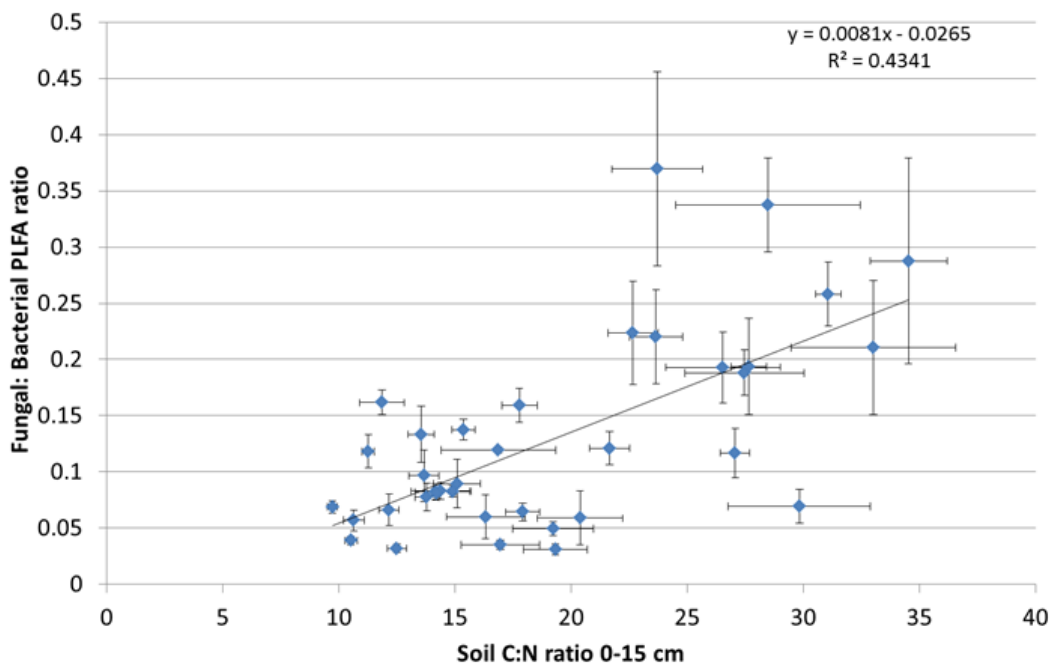


Figure 5. The relationship between ratio of fungal to bacterial-derived PFLAs and the soil carbon to nitrogen ratio, showing how high carbon, low nitrogen compounds are associated with greater fungal biomass, while substrates containing more nitrogen content are associated with more bacteria. Bars show variability within sites (standard error, n=5).

Results from the bacterial tRFLP analysis (Figure 6) indicated significant clustering of bacterial communities sampled from the same sites, with overlapping communities between similar sites. A multivariate analysis indicated that this measure was more variable than PLFA, with the main axis explaining only 8.8% of the variability. This analysis indicates that these communities are most strongly influenced by pH, with an outlier group on the second axis representing the five plots at North Walney, the only saltmarsh site in the series. It also shows that that communities in acidic sites are more variable than those in more alkaline soils. This pattern closely reflects that found by Griffiths and others (2010) working on sites sampled for the Countryside Survey in 2007.

Natural England's Long Term Monitoring Network: monitoring soils 2011 to 2016

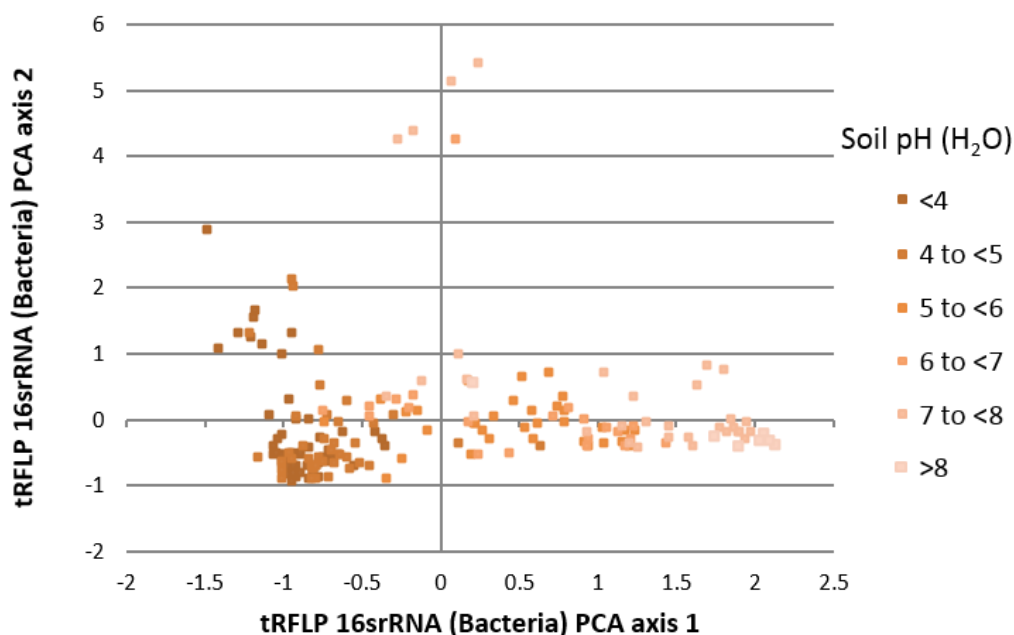


Figure 6. Characteristics of bacterial communities as determined using tRFLP, and described using principle components analysis to plot similarities on two axes explaining 14.8% of community variance. A colour scale has been used to indicate the range of soil pH in which these communities were found.

While bacterial communities may respond to changes in conditions within hours or days, soil mesofauna typically reflect conditions between monthly to multi-annual timescales. Few soil mesofauna samples have been identified, with only one site (Finglandrigg Woods), having all five samples analysed. The results so far suggest that in the top 8 cm of a square metre of soil mesofauna animals number between 20,690 and 216,450 (average 79,100) at Finglandrigg Woods, 142,443 at Lullington Heath and 316,718 East Dartmoor NNR (Yarner Wood). The numbers at Finglandrigg are close to the averages measured by the Countryside Surveys 1998 and 2007 for broadleaved woodland (~73,000 to 82,000 per square metre), while the numbers measured for Lullington heath and East Dartmoor NNRs are considerably higher than the Countryside Survey averages for these habitats (60,240 and 94,856 for heathland).

The 1998 and 2007 Countryside Surveys grouped animals into “broad taxa” and found average values for number of these “broad taxa” ranging between 3.28 and 5.81. Again, while Finglandrigg’s diversity of broad taxa is comparable (average 4.4 broad taxa), the two samples assessed at Yarner Wood and Lullington Heath supported 8 and 7 broad taxa. These results may indicate that our NNRs are supporting an unusually high population and diversity of soil organisms compared to the national picture.

The early results from this analysis suggest that the broad characteristics of the soil mesofauna community may reflect soil physical and chemical conditions. Early analysis suggests that the proportion of mites in the soil mesofauna community may be negatively correlated with bulk density, that lower calcium soils contain more Oribatid mites, and higher calcium soils contain more prostigmata mites, and that the proportion of mesostigmata mites increases with decreasing soil water content. These possible trends are based on analysis of very few samples and should be investigated further, once more samples have been analysed.

Natural England's Long Term Monitoring Network: monitoring soils 2011 to 2016

So far, the soil mesofauna communities analysed have been dominated by mites, and approximately half to three quarters of all animals were decomposer Oribatid mites (Figure 7). There are clear differences between communities even at low levels of taxonomic resolution. Analysis of the communities at higher levels of detail (Figure 8) shows greater differentiation between the habitats suggesting that the species composition of these communities may be sensitive indicators of environmental change, as demonstrated in previous studies (Behan-Pelletier, 1999).

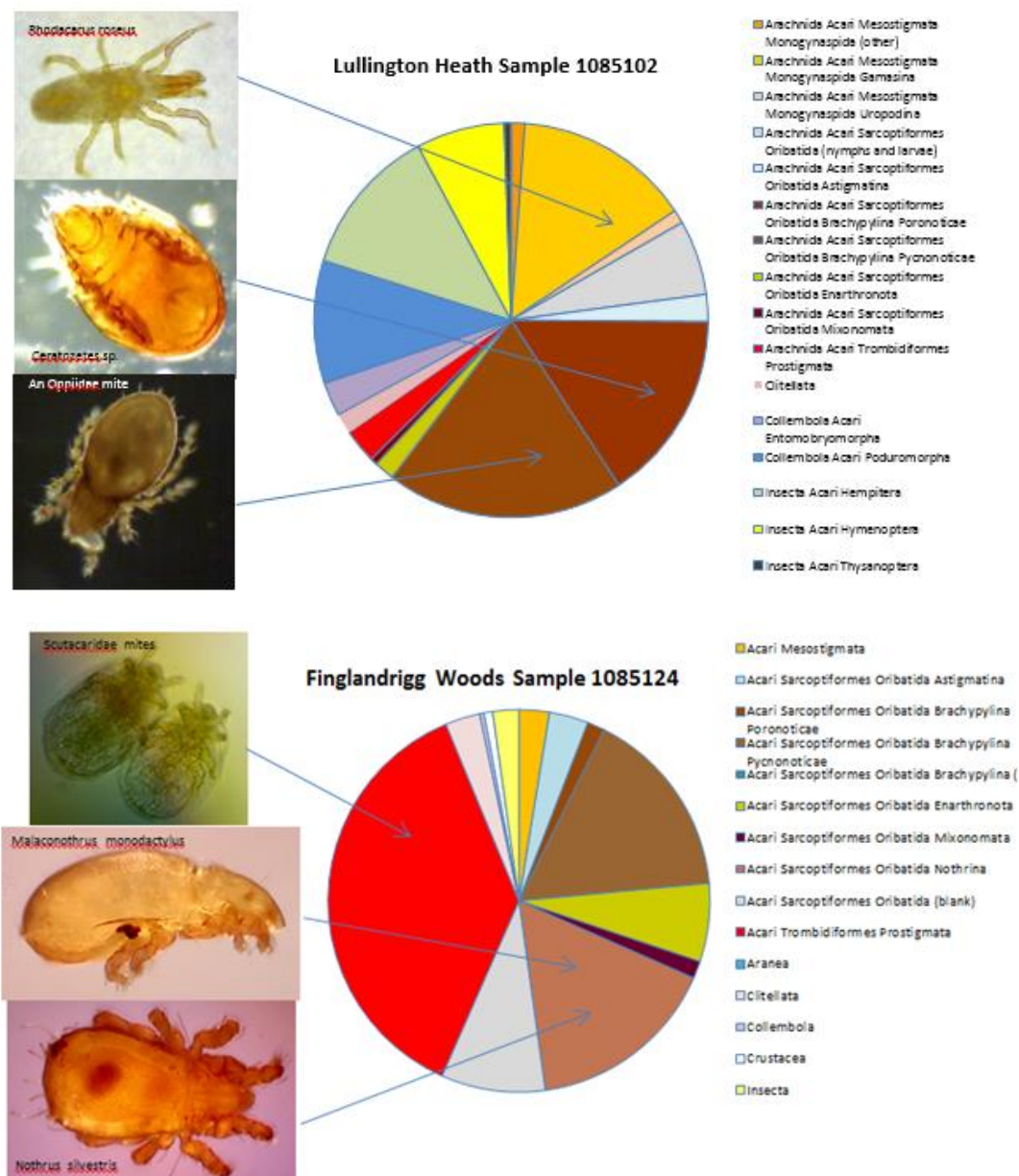


Figure 7 Examples of soil mesofauna communities from Lullington Heath, Finglandrigg Woods and East Dartmoor NNR. Different positions on this graph reflect differences in the dominant Oribatid mite communities, and also the localised prevalence of Scutacarid mites in one Finglandrigg sample.

Natural England's Long Term Monitoring Network: monitoring soils 2011 to 2016

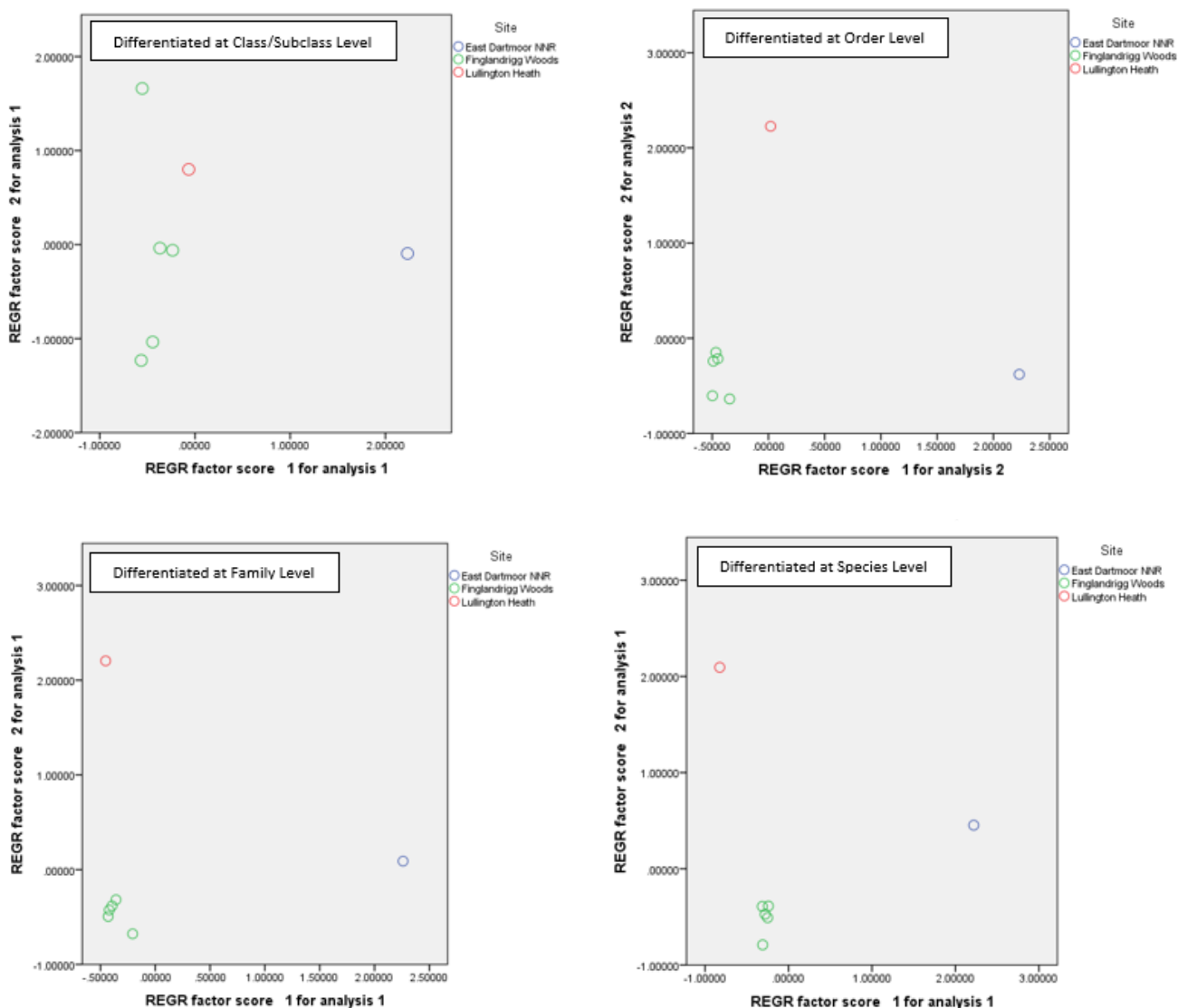
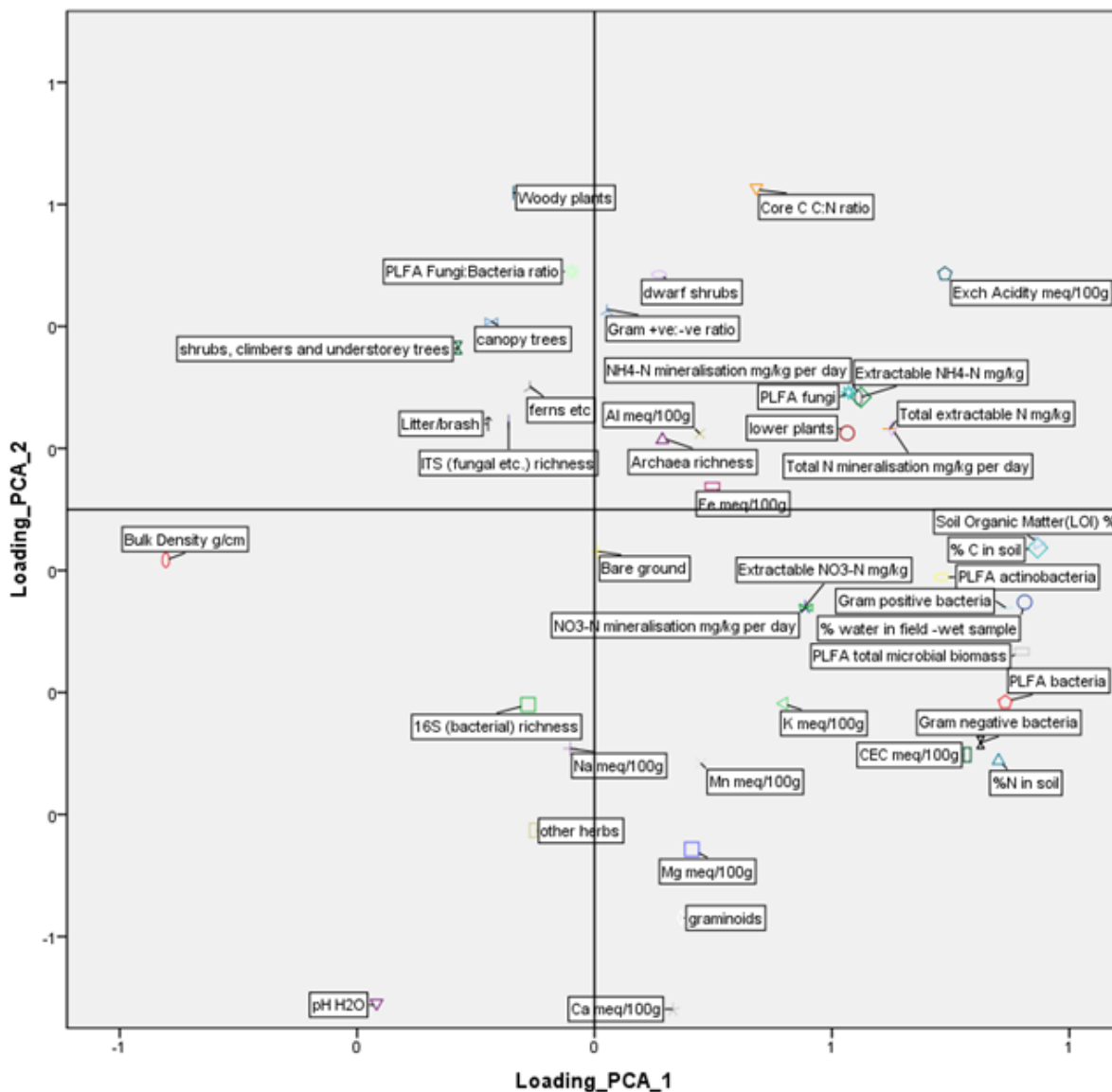


Figure 8 Impact of increasing taxonomic precision on the ability of soil mesofauna communities to distinguish between different communities. Numbers of individuals within groups were analysed using principle components analysis and plots of the first two principle axes (all explaining between 70.8 and 72.8% of the variance in the data).

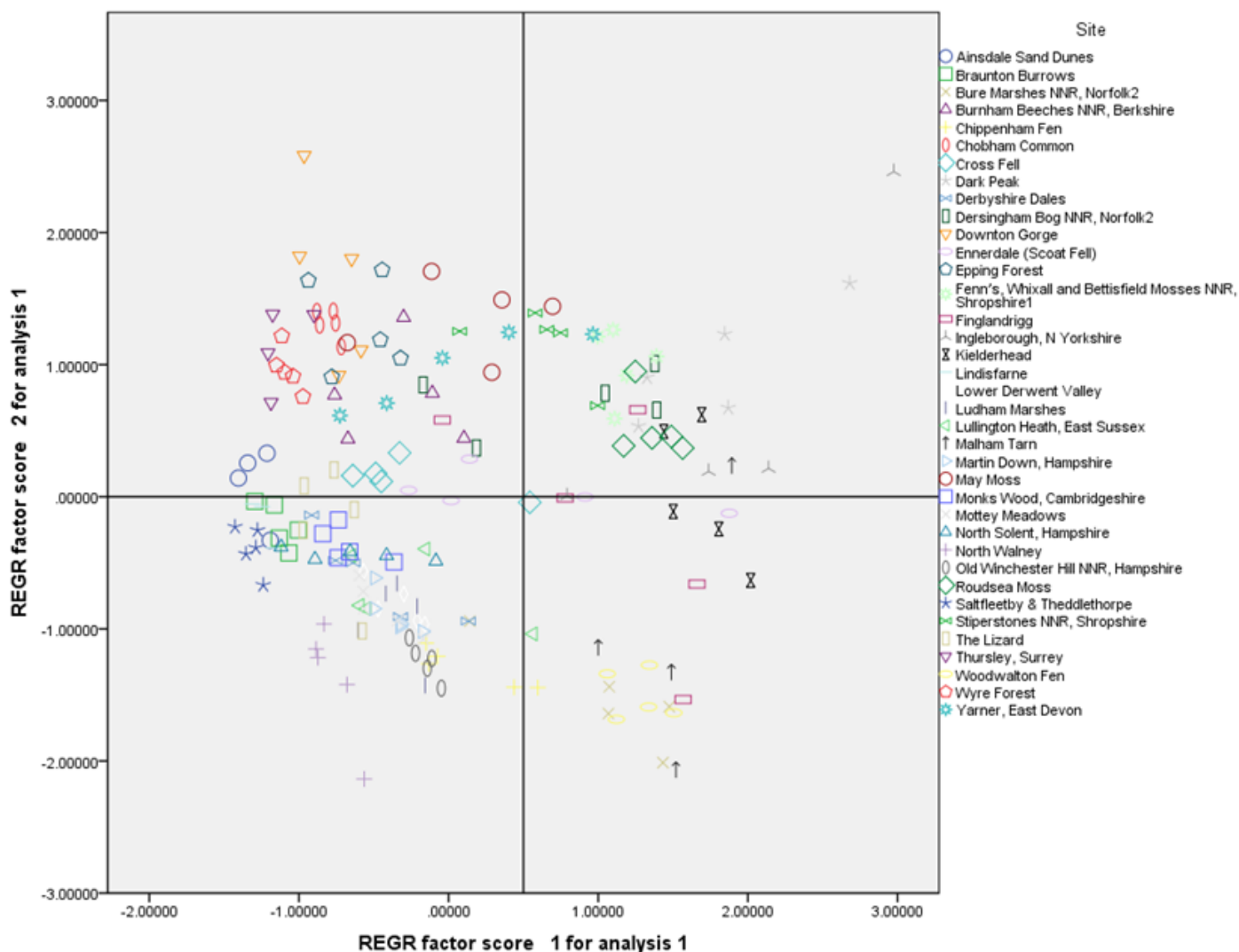
All the above-ground and below ground field and soil analytical attributes from the LTMN soils monitoring can be included in one analysis, to identify and visualise broad patterns in the natural environment. It is possible to draw graphs not only of the similarities and differences among the different sites (Figure 10), but to use the same axes to map out how the different attributes measured relate to this space (Figure 9). As the vegetation and soil conditions change during the course of the monitoring scheme, we should be able to track the path of these sites across this conceptual landscape, enabling us to identify their trajectory of change and the possible nature of their destination.

Natural England's Long Term Monitoring Network: monitoring soils 2011 to 2016



Figures 9 and 10 Loadings of a range of different soil and vegetation parameters on the axes of a principle components analysis for all LTMN soils monitoring data (above) and score on these 2 principle axes (which explain over 40% of the variance in the full data) for the sampling plots from each site. The position of each sampling plot on the graph below indicates its likely characteristics as described by the graph above.

Natural England's Long Term Monitoring Network: monitoring soils 2011 to 2016



Discussion and conclusions

The LTMN soils monitoring data has helped to describe how soil conditions vary across our semi-natural habitats, to identify interactions between these conditions, and indicate the relationship of these conditions with the organisms that carry out the functions of the soil. The data produced have proved compatible with those collected by the Countryside Survey, and further exploration of the relationship between these two data sets is likely to yield greater insight into the relationship between soils in some of our most valued semi-natural habitats and soils in the wider countryside.

The assessment of microbial communities, and the early results from analysis of the soil mesofauna communities, show a promising ability to distinguish sites, making these potentially sensitive tools to detect change. Furthermore, the data from this survey is contributing hugely to our scant knowledge of the composition and distribution of soil communities in England.

To help expedite the slow analysis of the mesofauna and nematode samples Natural England has allocated some funding towards using genetic metabarcoding (characterising the DNA from whole communities) on sub-samples of the communities to enable rapid identification of the organisms present.

Natural England's Long Term Monitoring Network: monitoring soils 2011 to 2016

A further sub-sample will be retained to enable individual specimens to be identified morphologically and their barcodes analysed individually, thus helping to identify the species from the community samples.

Genetic technology has advanced considerably since the LTMN soils monitoring started, and it is now common practice to use analysis of the range of 16SrRNA bacterial genes in the soil, rather than tRFLP, to characterise bacterial communities, although current widespread techniques do not provide reliable quantitative data.

We must consider carefully whether to embrace new technology that may be difficult to compare with the baseline information already collected, or whether to continue with the current set of techniques. The ideal situation would be to apply new techniques that provided richer information which can be converted into forms compatible with the older data. A research project attempting to determine how tRFLP fragments link to the bacterial barcodes from which they are derived would be extremely valuable.

There has been interest from other organisations in our soil monitoring protocol, and Natural England is working with researchers and other public bodies to coordinate our monitoring efforts with those of others. A wider network of associated monitoring sites, including agricultural land, will help to put the data we've collected into a wider context and further reveal the value of soils in semi-natural habitats. It is hoped that the LTMN data, available through the www.gov.uk website, will form the basis of future postgraduate studies and collaborative projects.

It is hoped that funding will become available for the analysis of the dried, archived samples for extractable phosphate using a range of analytical techniques which should help to overcome the initial problems of using the Olsen P technique on more acid soils.

One drawback of this monitoring programme is that all measures are based on samples collected during a single visit. This makes it difficult to measure soil functions, which must be measured over time with repeated measurements, and only one function (N mineralisation) has so far been measured on collected samples. Collaboration with local NNR staff or with researchers may reveal more about soil functions through repeated measures. For example, a decomposition study using nylon mesh teabags (Keuskamp and others, 2013) is planned for some of our wetland LTMN sites.

Having concluded the baseline Natural England staff and volunteers will now revisit some of the sites initially assessed in 2011 to determine changes over the last 6 years. This will present a new set of challenges, not least relocating the sampling plots in dense and ever-changing vegetation, but it will enable us to understand how environmental change is affecting the condition of our soils, the fascinating soil communities that inhabit them and the vital functions they carry out.

This monitoring programme for soils is the only ongoing long-term sampling programme currently assessing soils in the UK. Concentrating as it does on some of our most valued semi-natural and natural habitats, it cannot provide picture of what is happening to soils over most of country, in agricultural, afforested or urban environments. Without a wider soil monitoring programme we have little indication of the state of our wider soils, how they are changing and the problems or opportunities they may generate in the future.

Ignorance of the national state of our soils, will make it difficult to predict impacts and services such as flooding, carbon storage, greenhouse gas flux and other vital services required for a healthy and

Natural England's Long Term Monitoring Network: monitoring soils 2011 to 2016

productive environment. To understand the true national trends in soil would require a more widespread monitoring programme, which is beyond the current remit and resources of Natural England. However, this programme has demonstrated a range of sensitive indicators, including biological parameters, can be used to reveal the true nature of soils, and it is hoped that the LTMN soils monitoring will contribute to, and help us understand, the state of our soils nationally.

Further information

Natural England evidence publications are available to download from the Natural England Access to Evidence Catalogue <http://publications.naturalengland.org.uk/> For information on Natural England contact the Natural England Enquiry Service on 0300 060 3900 or e-mail enquiries@naturalengland.org.uk. In particular see:

[Taking the long view - an introduction to Natural England's long term monitoring network 2009 - 2016](#)
[Long Term Monitoring Network soils data and protocols](#)

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