British Ecological Society

Soil Health
A response from the British Ecological Society to the Environmental Audit Committee

22 January 2016

The British Ecological Society
'A world inspired, informed and influenced by ecology'

The British Ecological Society (BES) is the UK's academic learned society for ecological science and the oldest institution of its kind in the world, established in 1913. The BES has nearly 6,000 members, representing the full scope of ecological research and practice and breadth of ecological careers, from undergraduate students to established professionals.

The Society welcomes the opportunity to respond to the Committee's inquiry on Soil Health. We would also like to point the committee to the *Journal of Ecology's Virtual Issue on Soil*, from December 2014, edited by Richard Bardgett & Amy Austin:
http://www.journalofecology.org/view/0/VI_Soil.html

All 20 papers within this Virtual Issue are freely accessible, and have been selected to demonstrate the breadth and international scope of soil-related research, illustrating how ecologists are enhancing our understanding of the ecological and evolutionary significance of plant-soil interactions.

Summary

- Soil provides numerous services that are essential to human wellbeing and societal prosperity, including food production; storing and filtering water; storing carbon and regulating greenhouse gas emissions; and hosting an estimated quarter of the world's biodiversity. Soil 'health' is determined primarily by what function is prioritised.

- There are several threats to soil quality which impact on its ability to deliver benefits. These include localised impacts such as contamination, land use change and changes in nutrient status, as well as the impact of a changing climate.

- Soil formation is a long-term process - an average rate of one centimetre per century - therefore recovery rates for damaged soils are very slow.

- What constitutes a healthy soil depends on the service it is expected to deliver, and there is no single indicator suitable for all outcome measures of soil condition. Indicators of soil condition can be categorised as physical, chemical and biological; a monitoring programme should integrate all three.

- A soil strategy, linked to Government's 25-year plans for the environment, and food and farming, which includes sampling of a determined suite of nationwide sites at an appropriate temporal scale, is recommended.

- An effective strategy should incorporate both urban and agricultural soils; establish baseline data on soil condition; have a long-term commitment to monitoring and securing soil condition; include training provision and awareness raising, and be incorporated into decision-making processes.

British Ecological Society
Charles Darwin House, 12 Roger Street, London WC1N 2JU +44 (0)20 7685 2510
policy@britishecologicalsociety.org www.britishecologicalsociety.org

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Introduction

1. Soil health is the ability of soil to deliver key processes and ecosystem functions, and the benefits to society described later in this response. Soil health has been defined as:

> *"the continued capacity of soil to function as a vital living system, within ecosystem and land-use boundaries, to sustain biological productivity, promote the quality of air and water environments, and maintain plant, animal, and human health"*[1]

2. There are many different soil types, and soil profiles are highly diverse both laterally and vertically, with soils serving different functions both regionally and locally. Indicators of health are therefore specific to soil type and function; what is healthy for one soil type, may not be healthy for another.

What are the benefits that healthy soils can provide to society?

3. Healthy soils are both a living system of intrinsic value and a key natural capital asset:[2] they deliver numerous ecosystem services that are essential to human wellbeing and societal prosperity. Major global functions performed by soils include: food production; storing and filtering water; storing carbon and regulating greenhouse gas emissions; and hosting an estimated quarter of the world's biodiversity.[3,4,5]

4. Approximately 95% of global food production relies on soil, which supplies essential nutrients, water, oxygen and root support required by agricultural crops. Soil condition underpins agricultural productivity and food security.

5. Soils perform a buffering function that mitigates extreme weather events including flooding and drought. Healthy soils and the vegetation they support have a greater capacity to absorb precipitation during high intensity rainfall events, reducing peak river flow and flooding, and to store and retain water during dry periods, buffering plants against rainfall deficit. Healthy soils also continue to function better under extreme weather events, thereby securing future crop growth.

6. Soils play an important role in the provision of clean drinking water through their capacity to remove contaminants, for example metals or organic compounds, via processes including absorption at the land surface and the microbial transformation of contaminants into non-toxic forms[3].

7. As the major terrestrial reservoir of carbon (containing approximately 1500 billion tonnes),[6] soils have a significant influence on the global carbon cycle and atmospheric CO_2 levels. Degradation of carbon-rich soils releases significant quantities of CO_2 into the atmosphere. In the UK, peat soils in upland areas play a particularly important role in soil carbon storage, holding around 40% of UK soil carbon.[7]

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[1] Pankhurst, Clive, Bernard M. Doube, and V. V. S. R. Gupta. *Biological indicators of soil health*. Cab International, 1997
[2] Natural Capital Committee (2013), *The State of Natural Capital: Towards a framework for measurement and valuation*
[3] FAO and ITPS (2015), *Status of the World's Soil Resources (SWSR) – Technical Summary*. Food and Agriculture Organization of the United Nations and Intergovernmental Technical Panel on Soils, Rome, Italy.
[4] Parliamentary Office of Science and Technology (2015) *Postnote 502: Securing Soil Health*.
[5] Decaëns, T., et al. (2006) *The values of soil animals for conservation biology*. European Journal of Soil Biology 42: S23-S38.
[6] Scharlemann, J.P.W., Tanner, E.J.V, Hiederer, R. and Kapos, V. (2014), *Global soil carbon: understanding and managing the largest terrestrial carbon pool*, Carbon Management, 5(1), pp81-91.
[7] UK National Ecosystem Assessment (2011) *The UK National Ecosystem Assessment: Synthesis of the Key Findings*. UNEP-WCMC, Cambridge.

8. Healthy soils also play a significant role in regulating emissions of other potent greenhouse gases such as nitrous oxide (N_2O) and methane (CH_4). Agricultural soils are the major source of nitrous oxide emissions, and better soil management, including more efficient fertiliser use, can significantly regulate this flow.[8] Anaerobic soils (e.g. wetlands and peat) are a major source of natural methane emissions, whilst aerobic soils act as methane sinks[3].

9. Soils are home to approximately 25% of the world's biodiversity, including bacteria, fungi and invertebrates; 10 grams of soil can contain up to 10^6 species[3]. Soil biodiversity drives ecosystem functions and services such as soil formation, nutrient cycling, food production, and disease and pest control, and influences the structure and diversity of plant communities.[9]

10. Soil biodiversity also plays an important role in supporting human health, through the suppression of pathogens and provision of clean air, water and food.[10] Soil is also a major reservoir for biotechnological exploitation, with soil organisms the source of the majority of clinical antibiotics.[11]

11. These benefits are not exhaustive: Robinson *et al* [12] identify a number of additional ecosystem services that soils deliver, including the provision of goods such as peat and clay, and cultural services such as the support of recreational surfaces. Soil quality also cascades through wider ecological networks (i.e. plants and animals) and indirectly affects important ecosystem services such as pollination. Urban soils play a particular role in regulating temperature and air quality, and in the degradation of pollutants.[13]

12. The benefits that soils provide and the ecosystem services that they deliver cannot be considered in isolation: soils are a living ecosystem with complex interactions between their physical, biological and chemical components, and their ecosystem functions and processes. There will however be trade-offs between services: for example increasing agricultural productivity could be detrimental to water quality or biodiversity.

What are the consequences of failing to protect soil health for the environment, public health, food security, and other areas?

13. There are a range of immediate and future threats to soil health (or soil condition) which will severely compromise its ability to deliver the essential services listed above. Broadly, soil condition is compromised through either soil degradation (reduction in quality), or erosion (reduction in quantity), due to threats that act both generally (for example, climate change) and locally. **Importantly, because soil formation is a long-term process (an average rate of one centimetre per century), recovery rates for these ecosystem services are very slow**[7].

14. Research by Graves *et al*[14] has estimated the costs of soil degradation in the UK as between £0.9bn and £1.4bn per year, with a central estimate of £1.2bn. This is linked mainly to loss of organic

[8] The Royal Society (2011) *Reducing greenhouse gas emissions from agriculture: meeting the challenges of food security and climate change*. Meeting report. http://bit.ly/1ZYveFI

[9] Bardgett. R.D. and van der Putten, W.H. (2014). Belowground biodiversity and ecosystem functioning. *Nature*, 515, pp505-511.

[10] Wall, D.H., Nielsen, U.N., and Six, J. (2015) *Soil biodiversity and human health,* Nature, 528 (7580), pp69-76.

[11] D'Costa, V.M., McGrann, K.M., Hughes, D.W. & Wright, G.D. (2006). *Sampling the antibiotic resistome*. Science, 311: 374-377.

[12] Robinson, D.A., Hockley, N., Cooper, D.M., Emmett, B.A., Keith, A.M., Lebron, I., Reynolds, B., Tipping, E., Tyed, A.M., Watts, C.W., Whalley, W.R., Black, H.I.J., Warren, G.P. and Robinson, J.S. (2013), *Natural capital and ecosystem services, developing an appropriate soils framework as a basis for valuation,* Soil Biology and Biochemistry*,* 57, pp1023 – 1033.

[13] Durham University (2015) *'A nation that destroys its soils, destroys itself': Pathways towards the sound management of urban soil*

[14] Graves, A. R., et al. (2015) *The total costs of soil degradation in England and Wales.* Ecological Economics 119: 399-413.

content of soils (47% of total cost), compaction (39%) and erosion (12%). 80% of costs occur offsite, limiting the concern of those whose actions may be causing degradation.

Threats and impacts:

Agricultural land use

15. Soil carbon is a particularly important component of healthy soil, affecting its physical and chemical characteristics. Meta-analysis indicates that soil carbon stocks decline after land use changes from pasture to plantation,[15] and that cropping practices – the intensity and type of crops used, as well as the removal of crop residues from the land - impact upon soil organic carbon content.[16] Land management practices such as tillage, draining and persistent grazing also expose soil organic matter to oxidation, causing a loss of organic carbon.

16. This loss of carbon into the atmosphere will not only compromise the UK's ability to meet greenhouse gas emission targets, but also degrades soil structure, having major impacts on agricultural productivity, increasing costs of water purification and making land more vulnerable to climatic extremes.

Sealing of urban soils

17. The UK National Ecosystem Assessment (NEA) [7] highlighted the degradation of urban soils, stating that many of their supporting and regulating functions have been reduced or restricted through widespread sealing (covering soil with impenetrable surfaces) and degradation, with concomitant increases in hazards such as flooding.[17] The capacity of urban soils to regulate water, nutrient, pollutant and sediment transfer from the land surface continues to be compromised.

Nutrient status

18. The NEA states that changes in the nutrient status and pH of waters and soils in recent decades have had a significant impact on the delivery of regulating and provisioning ecosystem services. The enrichment of terrestrial and aquatic habitats with nitrogen, through fertiliser use, has resulted in substantial changes in plant productivity, plant species diversity and composition, the composition of soil communities, and accelerated rates of nitrogen cycling.

Contamination

19. The definition of a soil contaminant is beyond the scope of this response, however harmful substances or agents that have accumulated in the soil, often as a result of industrial activity, are a threat to biodiversity, can make soil non-productive and pollute groundwater[4]. Contaminants can be inorganic (such as arsenic, copper, lead, sulphur) and organic (acetone, benzene, DDT).[18]

[15] Guo, Lanbin B., and Gifford, R. M. (2002) *Soil carbon stocks and land use change: a meta analysis.* Global change biology 8.4: 345-360.
[16] Ogle, Stephen M., F. Jay Breidt, and Keith Paustian. (2005) *Agricultural management impacts on soil organic carbon storage under moist and dry climatic conditions of temperate and tropical regions*. Biogeochemistry 72.1: 87-121.
[17] Parliamentary Office of Science and Technology (2013) *Postnote 448 :Urban Green Infrastructure*
[18] For a list of priority contaminants see Martin I, Cowie C (2008) Compilation of data for priority organic pollutants for derivation of soil guideline values**,** Environment Agency, UK

20. High traffic volume and coal burning have been responsible for raising contaminant levels in the urban environment, and non-ferrous mineralisation and associated mining activities are a significant contributor to high levels of many inorganic contaminants in soil.[19]

Climate Change

21. Soil condition is both impacted by climate change, and important for resilience to it.[20] Predicted hotter, drier summers and warmer, wetter winters will increase the risk of wind erosion and soil drought in the summer, and the risk of soil erosion by water in the winter.[21] Conditions in areas where upland peat is found will probably be rarer in the UK under climate change, and there may be indirect effects on soil associated with climate-induced changes in land use.[17]

22. There is no current consensus on the impacts of climate change on soil carbon.[22,23]

What measures are currently in place to ensure that good soil health is promoted?

International Soil Policy

23. 2015 was the UN International Year of Soils, which aimed to raise awareness of the importance of soil health amongst the public, civil society and decision-makers. Soil condition is promoted in Target 15.3 of the UN Sustainable Development Goals, which aims by 2030 to "combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral world".

Soil Policy in the EU

24. There is no specific EU legislation on soil, with a proposed Soil Framework Directive withdrawn in 2014 after sustained opposition from Member States, including the UK. The European Commission states that measures contained within the Common Agricultural Policy, Water Framework Directive and other legislation "are not sufficient to ensure an adequate level of protection for all soils in Europe".[24]

25. The EU's Seventh Environmental Action Plan (2013) states that soil should be adequately protected by 2020, and calls on the Union and Member States to reflect on "how soil quality issues could be addressed using a targeted and proportionate risk-based approach within a binding legal framework".[25]

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[19] Ander, E. Louise, et al. (2013) *Methodology for the determination of normal background concentrations of contaminants in English soil.* Science of the Total Environment 454: 604-618.
[20] De Vries, F.T. and R.D. Bardgett (2015) Climate change effects on soil biota in the UK. Terrestrial Biodiversity Climate change Impacts Report Card Technical paper. Bodsey Ecology Limited, Huntingdon, UK.
[21] Natural England, 2015, *Summary of Evidence: Soils*.
[22] Davidson, E. A., and Janssens, I.A., (2006) *Temperature sensitivity of soil carbon decomposition and feedbacks to climate change*. Nature 440.7081: 165-173.
[23] Barraclough, D., Smith, P., Worrall, F., Black, H.I.J. and Bhogal, A. (2015) *Is there an impact of climate change on soil carbon content in England and Wales?*, European Journal of Soil Science, 66 (3):451-462.
[24] http://ec.europa.eu/environment/soil/index_en.htm
[25] DECISION No 1386/2013/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 20 November 2013 on a General Union Environment Action Programme to 2020 '*Living well, within the limits of our planet*'

Soil Policy in England[26]

26. *'Safeguarding our Soils: A Strategy for England'*[27], introduced by the Labour Government in 2009, established the goal that "by 2030, all England's soils will be managed sustainably and degradation threats tackled successfully". This goal was reiterated in the Coalition's 2011 Natural Environment White Paper[28] (NEWP), which also established commitments to undertake a significant research programme on soil health and to reduce peat use to zero by 2030. In 2015, the Committee on Climate Change recommended the creation of a comprehensive action plan by the end of 2016 to deliver these policy aspirations.[29]

27. While there is no specific legislation protecting soil in England, it is protected indirectly through laws governing the control of pollution and management of contaminated land, and via conservation legislation.

Agriculture

28. Under the CAP, farmers in England must adhere to three Good Agricultural and Environmental Condition (GAEC) requirements in order to receive Basic Payment Scheme payments. Farmers must:
- ensure minimum soil cover (vegetation, cover crops, trees, stubble or crop residues) unless there is a valid agronomic justification (e.g. pest, disease or weed control; heathland restoration; outdoor pig or poultry production) (GAEC 4);
- manage land to minimise soil erosion through appropriate cropping practices and structures, livestock management, and appropriate use of machinery (GAEC 5);
- maintain levels of organic matter in soil by avoiding burning stubble and crop residues (GAEC 6).

29. No regulations or guidance are provided on other aspects of soil health such as soil fauna, microbiodiversity and structure. The guidance on soil standards provided to farmers by Defra has been significantly reduced the last five years, with just 16 pages of guidance for the 2015 CAP[30] compared to 76 pages in 2010.[31]

Planning and construction

30. The National Planning Policy Framework provides only minimal guidance on promoting soil health, stating that the planning system should protect and enhance soils, and prevent the adverse effects of unacceptable levels of pollution.[32] Planning authorities "should not identify new sites or extensions to existing sites for peat extraction". There is no specific policy framework for urban soils, despite the importance of their health in delivering vital ecosystem services including flood mitigation.[13] Defra has published a voluntary "code of practice" on the sustainable use of soils on construction sites.[33]

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[26] Soil policy is a devolve issue, and in our response we focus primarily on the English context.
[27] Defra (2009) *Safeguarding our Soils: A Strategy for England*
[28] HM Government (2011) *The Natural Choice: Securing the value of nature*
[29] Committee on Climate Change (2015) *Reducing emissions and preparing for climate change: 2015 Progress Report to Parliamen.t*
[30] Defra (2015) *Cross compliance in England: soil protection standards*
[31] Defra / Rural Payments Agency (2010) *Single payment scheme: Cross Compliance Guidance for Soil Management*
[32] The 2009 soil strategy proposed producing a toolkit for planning authorities to better account for soil function; however, this has not been produced.
[33] Defra (2009) *Construction Code of Practice for the Sustainable Use of Soils on Construction Sites.*

Peat

31. The NEWP established a goal to limit peatland degradation by reducing peat use to zero by 2030, and created the Sustainable Growing Media Task Force to advise on this process. The Task Force published its road map in 2011[34], and in response, the Government outlined a number of steps to support the horticultural sector in this transition.[35] This policy was due for review in 2015; however, it appears that this has not yet taken place.

32. Peatlands were identified in Defra's Payment for Ecosystem Services Action Plan (2013)[36] as a potential test case for PES, and Government supported the IUCN in developing the UK Peatlands Carbon Code to facilitate business investment in peatland restoration.[37] A number of collaborative projects, for example the Moors for the Future Partnership are working locally to restore peat soils.[38]

How could soil health best be measured and monitored?

33. A wide range of measures exist that can indicate the physical, chemical and biological condition of the soil. It is important to distinguish between indicators that are sensitive to land management (for example, certain groups of nematodes) and indicators that have an established, mechanistic link with soil functioning (for example, nitrifying bacteria). What constitutes a healthy soil depends on the service required; productive agricultural land will have different optimal chemical, physical and biological properties to soils supporting woodland, peatlands, meadows, or urban environments.

34. A good indicator of soil condition should exhibit several properties:

- Strong correlation with the outcome measure of interest (i.e. the process or function associated with the desired land use. See Appendix I);
- sensitivity to variations in land management practices and climate;[39]
- temporal robustness (i.e. minimal fluctuations over short timescales);
- comparability across scales;
- a standardised sampling methodology;
- complementarity to other indicators;
- ease of interpretation for scientific and policy audiences;[40]
- cost efficiency.

35. Indicators of soil condition can be categorised as physical, chemical and biological, and a monitoring programme designed to obtain a comprehensive picture of soil health should integrate all three types. **There is no single indicator suitable for all outcome measures of soil condition.**

Physical indicators

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[34] Knight, A. (2012) *Towards Sustainable Growing Media: Chairman's Report and Road Map*, Sustainable Growing Media Taskforce
[35] Defra (2013) *Government Response to the Sustainable Growing Media Task Force*
[36] Defra (2013) *Developing the potential for Payments for Ecosystem Services: an Action Plan*
[37] IUCN UK National Committee Peatland Programme (2015) *Peatland Code*
[38] http://www.moorsforthefuture.org.uk/
[39] Doran, J. W. & Zeiss, M. R. (2000) Doran, J. W., & Zeiss, M. R. (2000). *Soil health and sustainability: managing the biotic component of soil quality*. Applied Soil Ecology, 15(1), 3-11.
[40] Bispo, A. et al (2009) *Indicators for Monitoring Soil Biodiversity*. Integr. Environ. Assess. Manag. 5, 717

36. Physical indicators include a range of measures of the soil’s texture, degree of compaction and response to physical stresses. The physical properties of soil, including aggregate stability and density, can be a key determinant of soil condition.

37. These analyses of the physical structure of soil provide an indication of its ability to resist erosion, hold or filter water and its suitability as a habitat for microorganisms and plant growth. Physical structure is a particularly good indicator for healthy agricultural soils, can be a proxy for several other processes or properties, and is relatively simple to evaluate.

Chemical indicators

38. The soil's physical, chemical, and biological properties have wide ranging impacts on chemical indicators such as soil nutrient content and pH level, as well as plant growth. In agricultural soils, pH level has a strong correlation with the nutrition, growth and yields of the crops grown. Levels of heavy metals are an indicator of soil contamination.

Biological indicators

39. Biological indicators include assessments of the abundance and diversity within certain taxonomic groups such as earthworms, mites or mycorrhizal fungi; the quantification of biomass in total or within such groups; and measures of enzyme activity. These measures indicate the processes taking place within the soil and the overall state of the soil ecosystem. For example, individual groups of soil organisms and the interactions between these groups have been shown to link to processes of carbon and nitrogen cycling.[41] New tools such as DNA-metabarcoding[42] and complex network analysis, can not only monitor biodiversity in soils, but also better understand how organisms interact and affect ecosystem functioning.

40. Soil carbon, assessed through soil organic matter content (SOM) holds soil together, and supports soil fertility and biodiversity. Organic matter is highly variable across soil types, but a decline in content over time is often a useful indicator of damage to soils. Many of the biological indicators listed above, such as species abundance and biomass, are closely correlated with organic matter content. Organic carbon underlies soil physical structure and chemical composition.

41. There are two main methods for estimating soil organic matter. The Walkley Black[43] technique uses an oxidising agent, potassium dichromate, to react with the organic matter in the soil, whilst in the Loss on Ignition (LOI) approach, mass is estimated as organic matter is burned off under controlled conditions.[44]

42. Research on floodplain meadows suggests that vegetation could be used as a proxy for this type of soil structure, since characterising the hydrological requirements of plant species largely reflects the porosity of the underlying soil.[45,46,47,48] Palmer and Holman demonstrated that soil structure was the

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[41] De Vries et al. (2013) *Soil food web properties explain ecosystem services across European land use systems*. PNAS 110:14296-14301

[42] Taberlet, Pierre, et al. (2012) *Towards next-generation biodiversity assessment using DNA metabarcoding*. Molecular Ecology 21.8 (2012): 2045-2050.

[43] Walkley, A. and Armstrong Black, I. (1934) *An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method,* Soil Science, 37 (1), pp29-38

[44] For a comparison of methods, see Wang, X., Wang, J. and Zhang, J. (2012) *Comparisons of Three Methods for Organic and Inorganic Carbon in Calcareous Soils of Northwestern China*, PLoS ONE 7(8).

[45] Araya, Y.N., Silvertown J., Gowing, D.J.G., McConway K.J., Linder H.P. and Midgley, G. (2011) *A fundamental, eco-hydrological basis for niche segregation in plant communities*. New Phytologist, 189, 253-258

most powerful predictor of vegetation type out of an array of environmental factors.[49] Further development is required to identify the best method and most appropriate indicator species, but an indicative list has been developed through the Floodplain Meadows Partnership – further information is available at this website.[50] 'Ellenberg vegetation values', which reflect the ecological behaviour of plant species, have also been used to summarise complex environmental factors including soil moisture content for many years.[51]

43. Faber *et al*[52] present a number of criteria by which the usefulness of biological indicators could be assessed. These include the extent to which specialist skills and equipment are required; cost efficiency; policy relevance and ease of comprehension; sensitivity to soil type, land use and disturbance; and standardisation. An extensive list of potential physical, chemical and biological indicators of soil health is provided in Appendix I.

Existing monitoring systems

44. There are 52 known soil monitoring programmes worldwide.[53] Chemical indicators of soil condition are most commonly used, including measures of nutrient content, especially copper, iron and zinc (40 programmes), soil pH (36 programmes), and different measures of nitrogen (20 programmes). Physical indicators include particle size analysis, soil water characteristics, soil moisture and aggregate stability (29 programmes). Biological indicators are less common, used across 19 programmes, with indicators including abundance or biodiversity of fauna at different scales. 5 programmes measure enzymatic activity. The Biological Indicator of Soil Quality (BISQ) used in the Netherlands' nationwide soil monitoring system is deemed amongst the most advanced soil monitoring systems.[38,54]

45. There are numerous existing research projects in the UK that offer a wealth of data and expertise on soil, including at the NERC UK Soil Observatory,[55] Rothamsted,[56] the James Hutton Institute,[57] Centre for Ecology and Hydrology,[58] and within the University sector. The NERC Soil Security programme currently funds consortium projects, fellowships and PhD studentships, and aims to "deliver improved forecasts of the response of the soils system to changes in climate, vegetation or

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[46] Gowing, D.J.G., Lawson, C.S., Youngs, E.G., Barber, K.R., Prosser, M.V., Wallace, H., Rodwell, J.S., Mountford, J.O. and Spoor, G. (2002). *The water-regime requirements and the response to hydrological change of grassland plant communities*. Final report to DEFRA (Conservation Management Division,) London. Project BD1310.
[47] Silvertown, J., Dodd, M.E., Gowing, D.J.G. and Mountford J.O. (1999). *Hydrologically-defined niches reveal a basis for species richness in plant communities*. Nature, 400,
[48] Silvertown, J., Araya, Y. N. & Gowing, D. J. (2015) *Hydrological niches in terrestrial plant communities: a review*. Journal of Ecology, 103, 93–108
[49] Palmer, R.C. and Holman, I.P. (2002) *Soil survey of the Lower Derwent ings*. National Soil Resources Institute Study no. SR9058V,Cranfield University, York.
[50] http://www.floodplainmeadows.org.uk/
[51] Schaffers, André P., and Karlè V. Sýkora. (2000) *Reliability of Ellenberg indicator values for moisture, nitrogen and soil reaction: a comparison with field measurements*. Journal of Vegetation science: 225-244.
[52] Faber, Jack H., et al. (2013) The practicalities and pitfalls of establishing a policy-relevant and cost-effective soil biological monitoring scheme. *Integrated environmental assessment and management* 9.2: 276-284.
[53] Government of Alberta, A. A. and F. P. and E. S. E. S. D. E. S. and R. B. Soil Quality Monitoring Programs: A Literature Review - Results and Discussion. at http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/aesa8536
[54] BISQ takes measurements across 300 randomly selected locations, stratified by land use and soil type, across a 6-year cycle. It measures environmental information such as land use and climate, bacterial community biodiversity and functions, and monitoring of species groups such as mites and earthworms. The scheme aims to establish the abundance and diversity of soil organisms across different soil types and land uses, estimate the impact of land management, and establish reference states of healthy soils.
[55] http://www.ukso.org/
[56] http://www.rothamsted.ac.uk/sustainable-soils-and-grassland-systems
[57] http://www.hutton.ac.uk/category/area-interest/soil-research
[58] https://www.ceh.ac.uk/our-science/science-areas/soil

management at scales of analysis which match the scale of decision making".[59] BBSRC's SARISA programme aims to improve understanding of agricultural soil and rhizosphere interactions to underpin the development of agricultural ecosystems.[60]

46. Several recent EU funded projects have focussed on understanding the role of soil biodiversity in ecosystem function and developing bioindicators. For example, EcoFINDERS,[61] which included 23 partners from European 10 countries, aimed to increase knowledge of soil biodiversity and its role in ecosystem services across different soils, climate types and land uses; to standardise methods and operating procedures for characterising soil biodiversity and functioning, and to develop of bioindicators.[62]

How could the Government develop a strategy for tracking soil health? And what further measures should the Government and other organisations consider in order to secure soil health?

47. The role of soil in the delivery of many vital societal benefits requires a commitment from Government akin to that for water and air. A soil strategy, linked to Government's 25-year plans for the environment, and food and farming, which includes sampling of a determined suite of nationwide sites at an appropriate temporal scale, is recommended.

48. An effective strategy should:
- incorporate both urban and agricultural soils;
- establish baseline data on soil condition;
- have a long term commitment to monitoring and securing soil condition;
- include training provision and awareness raising;
- be incorporated into decision-making processes.

Baseline data

49. The strategy should first ascertain a robust baseline of soil data, from which to establish how and where soil changes over time. The Countryside Survey[63] (the continuation of which Defra funding is not currently in place) provides historical data that should be incorporated where possible, in addition to the Environmental Change Network data and existing projects mentioned in paragraph 45. We recommend that a strategy for tracking soil health begins by bringing existing research initiatives and datasets together, and expanding on them. The BES is well placed to provide access to individuals with expertise in this regard.

50. Comprehensive data collection would also shed light on the extent of soil contamination in the UK, and guidance on what the 'normal' levels of contaminant concentrations in English soils should be has already been developed by the British Geological Survey.[64] Monitoring should also identify especially unique, threatened or valuable soils that require particular protection.

Long Term Commitment

51. An effective strategy requires a long-term commitment from Government to monitor and address how soils change over time. The biggest factors influencing soil change occur through climate

[59] http://www.nerc.ac.uk/research/funded/programmes/soilsecurity/
[60] http://www.bbsrc.ac.uk/funding/opportunities/2013/2013-gfs-sarisa/
[61] http://esdac.jrc.ec.europa.eu/projects/ecoFinders
[62] See recent special issue of *Applied Soil Ecology* (2016), 97, pp1-134.
[63] http://www.countrysidesurvey.org.uk/science-and-research/work-packages/soils
[64] http://www.bgs.ac.uk/gbase/NBCDefraProject.html

change, land use change, urbanisation and invasive species. The UK NEA states that there is insufficient knowledge regarding the recovery of soils under a changing climate, with competing explanations for changes in and vulnerability of the UK's soil carbon stocks, and soil's role in water purification. Further research is needed to understand the dynamics of soil water, how it is influenced by drivers such as climate change, and the impacts on nutrient and carbon cycling.

52. To understand the drivers and implications of soil change, a holistic approach to both research and monitoring is needed over a sustained time period. The Government's 25-year plans for the environment, and food and farming provide a timely framework from which to incorporate this approach.

Training Provision & Awareness Raising

53. A soil strategy which includes training provision for ecologists, land users and citizens to monitor and measure soil condition would enable more frequent data collection at a range of sites across the UK. Relatively simple training on the visual aspects of soil structure and colour is a cost effective way of ascertaining soil condition data at the local level, helping to flag changes in soil in a timely way. A range of tools can be used for this type of training; for instance, the James Hutton Institute has produced an app for Scottish soils that allows organic carbon assessment via an uploaded smartphone photograph.[65]

54. Greater awareness of the importance soils and the role they play in delivering societal benefits would bolster the strategy, through education, and public engagement and stakeholder activities.

Decision-making

55. An effective strategy for soil health integrates soils into decision making across government departments, including land use and planning and agricultural policy. This could include the bolstering of guidance for promoting good soil health in the National Planning Policy Framework, and a specific policy framework for planning and urban soils. Existing guidance such as the Defra voluntary "code of practice" on the sustainable use of soils on construction sites could also be made more robust, with more incentives for implementation of best practice.

56. Implementation of the strategy should align with existing policies such as the Scottish Soil Framework,[66] and soil policy within the Natural Resources policy statement in Wales.

Measures to improve soil health

57. There is a growing body of research on interventions that can be used to improve soil health and be included in the strategy;
    - The addition of organic matter to arable soils to increase soil carbon content.[67,68,69,70] This can be achieved through addition of plant material; the processing and reintroducing organic

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[65] http://sifss.hutton.ac.uk/
[66] http://www.gov.scot/Publications/2009/05/20145602/0
[67] WRAP, DC-Agri project. http://www.wrap.org.uk/content/digestate-compost-agriculture
[68] Walsh, J. J., Jones, D. L., Edwards-Jones, G., & Williams, A. P. (2012). *Replacing inorganic fertilizer with anaerobic digestate may maintain agricultural productivity at less environmental cost.* Journal of Plant Nutrition and Soil Science, *175*(6), 840-845.
[69] Roig, N., Sierra, J., Martí, E., Nadal, M., Schuhmacher, M., & Domingo, J. L. (2012). *Long-term amendment of Spanish soils with sewage sludge: Effects on soil functioning*. Agriculture, ecosystems & environment, 158, 41-48.
[70] Institute of Organic Training & Advice: Research Review: Compost: the effect on nutrients, soil health and crop quantity and quality (This Review was undertaken by IOTA under the PACA Res project OFO347, funded by Defra)

wastes;[71] and reversion of arable grassland to wildflower grasslands, which have higher carbon content due to different rooting lengths[72] and a greater mass of roots.

- Changes in stock management to reduce the compaction of soils, and changes in crop management such as longer crop rotations, reduced tillage and cover crops.[4]
- Tree planting to retain soil structure and reduce flooding.
- Remediation of severely contaminated soils. Current methods can be expensive; however, there are innovative opportunities to pioneer new soil decontamination techniques.
- Particular mention should be made of interventions to restore peat soils, due to their importance in terms of carbon storage and flood resilience. There is widespread degradation to UK peatland soils by drying through loss of Sphagnum, gripping, erosion, gullying and burning (both managed and wildfire).[73] The Scottish Assembly has committed funding for peatland restoration[74] over a 5-year period; similar commitments would be welcome from the other UK nations, and would accompany business funding via the IUCN Peatland code.

What role (if any) should soil health play in the Government's upcoming 25-year plan for the natural environment?

58. Identifying solutions to mitigate the threats of soil degradation is inherently interdisciplinary, and solutions must be assessed in the light of other concerns with which soil is interwoven, such as water and biodiversity.[75] The Government's 25-year plan for the environment provides an opportunity to incorporate soil health policy and practice in an ecosystems approach, and the inclusion of soil health in the plan is essential. In response to the Natural Capital Committee report, Government responded that a 25-year plan will initially look to address outstanding natural capital monitoring and data issues[76] providing further opportunity to link with the monitoring and data availability and analysis within a soil monitoring programme.

59. Furthermore, soil should play an integral role in the Government's 25-year plan for food and farming. Given that these two plans are being developed separately, it is essential to ensure that soil management is joined up, and given due prominence across each strategy. Secretary of State for the Environment, Food & Rural Affairs, Liz Truss stated *'I want us to be making more integrated decisions at the levels of catchments and landscapes, not single species or natural features'*.[77] The 25-year plans provide an ideal opportunity for integrated decision-making, particularly given our knowledge of the importance of soil structure in resilience to flooding events and catchment management.

Further information

The BES is happy for our response to be made available publicly. If you have any questions about the content of this response or about the work of the BES, please contact Jackie Caine, Policy Manager on policy@britishecologicalsociety.org or 0207 685 2510.

[71] http://www.robustdurham.org.uk/

[72] Carbon storage by habitat: Review of the evidence of the impacts of management decisions and condition of carbon stores and sources (NERR043). Natural England 29 May 2012.

[73] Bain, C.G., Bonn, A., Stoneman, R., et al. (2011) IUCN UK Commission of Inquiry on Peatlands. IUCN UK Peatland Programme, Edinburgh.

[74] http://www.snh.gov.uk/climate-change/taking-action/carbon-management/peatland-action/

[75] http://www.cisl.cam.ac.uk/news/blog/why-doesnt-soil-get-same-attention-climate-change#sthash.y5zZmxvS.dpuf

[76] Defra (2015) *The government's response to the Natural Capital Committee's third State of Natural Capital report*.

[77] Open Environment speech by Elizabeth Truss, Delivered on: 14 October 2015 (Transcript of the speech, exactly as it was delivered) https://www.gov.uk/government/speeches/open-environment-speech-by-elizabeth-truss

Appendix I

Potential indicators of Soil Health

Type	Variable	Soil condition/process indicated
Physical		
	Aggregate stability	Erosion, compaction
	Available water capacity	Suitability for plant growth, leaching of nutrients
	Bulk density	Structural support, water and solute movement, and soil aeration.
	Infiltration	Ability to allow water movement into and through the soil profile.
	Slaking	Stability of soil aggregates, resistance to erosion, suggests how well soil can maintain its structure to provide water and air for plants and soil biota when it is rapidly wetted.
	Soil crusts	Crust indicates poor infiltration, a problematical seedbed, and reduced air exchange between the soil and atmosphere. It can also indicate that a soil has a high sodium content that increases soil dispersion when it is wetted by rainfall or irrigation.
	Soil structure and macropores	Important soil functions related to soil structure are: sustaining biological productivity, regulating and partitioning water and solute flow, and cycling and storing nutrients. Soil structure and macropores are vital to each of these functions based on their influence on water and air exchange, plant root exploration and habitat for soil organisms.
Chemical		
	Soil pH	Wide ranging influences on soil's physical, chemical, and biological properties and processes, as well as plant growth. The nutrition, growth, and yields of most crops decrease where pH is low and increase as pH rises to an optimum level
	Heavy metals: identify and quantify	Pollutants
	Nutrients (e.g. N, P, K, S, NH4, Mg, Ca): identify and quantify, and distinguished between total stocks of C, N, P and available fractions.	Nutrient content of soils is strongly associated with land use and habitat type. Agricultural land requires high levels of nutrients whilst low nutrient levels encourage species rich plant communities
Biological		
	Nematodes: abundance, community	Recycling of nutrients (nitrogen cycling and decomposition). Maturity indices respond to a variety of land management techniques

	composition, diversity, maturity index	
	Earthworms (annelida): abundance, diversity, functional diversity	Modify the physical structure of soils by producing new aggregates and pores, which improves soil tilth, aeration, infiltration, and drainage. Participate in plant residue decomposition, nutrient cycling, and redistribution of nutrients in the soil profile
	Mites: abundance, community composition, diversity	Recycling of nutrients. Community structure strongly correlates with land use type
	Protists: community composition	Sensitivity to nitrogen content, heavy metals, land use
	Collembola: taxonomic and functional diversity	Predominant species' reflect pH, water level capacity and organic matter content
	Mycorrhizal macrofungi: taxonomic and functional diversity	Nutrient cycling (N, P, water) and heavy metal uptake
	Enchytraeids, abundance, diversity at each trophic level	Formation of soil structure, decomposition of organic material
	Soil Organic Matter (SOM)	Indicative of soil structure, aggregation, water retention, soil biodiversity, absorption and retention of pollutants, buffering capacity, and the cycling and storage of plant nutrients. Sensitive indicator of changes in soil quality due to changes in vegetation growth. SOM positively correlates with soil fertility.
	Bacteria, archaea, and fungi: abundance, diversity, Microbial Biomass Carbon (MBC), fungal: bacterial biomass ratio.	Soil microorganisms are involved in several processes that influence soil quality (e.g. respiration, release of nitrogen) and microbial biomass changes rapidly in response to changes in soil properties (e.g. rainfall, management practices). Fungal:bacterial biomass ratio is related increased efficiency of carbon and nitrogen cycling.
	Fluorescein diacetate hydrolase (FDA)	As a measure of the microbial activity in soil, FDA indicates processes contributing to available nitrogen and carbon. Sensitive indicator of soil quality change due to climatic variation.
	Mycelium hyphae: biomass	Formation of soil structure
	Ammonia-oxidising bacteria and Archaea, ammonium production (NH_4^+)	Ammonification, accessibility of a critical nutrient for plant growth
	Nitrifying bacteria: nitrate production (NO_3^-)	Nitrification, accessibility of a crucial nutrient for plant growth