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25 Year Environment Plan Outcome Indicator E7: Healthy soils – Progress report

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Department for Environment Food & Rural Affairs

NCEA Natural Capital and Ecosystem Assessment

Contents

1. Introduction

Healthy soils are critical for the delivery of ecosystem services such as food production, water regulation, biodiversity support, and carbon storage. Maintaining soil health is crucial for soils to be resilient to climate change impacts, including increased flooding and drought. The 25 Year Environment Plan acknowledges this significance by including ‘soil health’ as one of 66 indicators of environmental change in the Outcome Indicator Framework. These indicators will help to show how the environment is changing over time and support the assessment of policies and other interventions.

The Environment Agency's State of the Environment Report (2019) indicates that soil health in England faces several pressures such as compaction, erosion, and agricultural intensification. Improving soil health offers a multitude of benefits, including increased agricultural yields, reduced flooding risks, and improved air quality.

Effective soil management requires the ability to measure and track changes in its health over time. However, assessing soil health presents a significant challenge due to its complex nature, encompassing physical, chemical, and biological properties. England’s soils also boast a diverse range of soil types, climates, and land uses.

Therefore, we have been developing a standardised national soil health indicator that will enable several benefits:

- **Comprehensive Monitoring:** Track changes in soil health over time at a national scale.
- **Informed Land Management:** Guide practices that promote soil health and overall sustainability.
- **Effective Communication:** Clearly communicate soil health status to policymakers and the public.
- **Objective Measurement:** Provide a consistent and unbiased measure for comparison across different regions and land uses.
- **Streamlined Data Collection:** Improve efficiency of monitoring programmes.

Significant progress has been made towards the development of a soil health indicator for England. In June 2023, JNCC published a proof-of-concept study that proposed a framework for assessing and conveying soil health at the field level (Harris *et al.*, 2023). The study defined soil health as “soils’ ability to contribute to the delivery of selected ecosystem services.” The ecosystem services it focused on were climate regulation (carbon storage), water regulation (runoff reduction), biodiversity support, and food/fibre production potential.

The development of the 25 Year Environment Plan Outcome Indicator Framework indicator will build on this work, adapting it for application at a national scale, with the ability to display soil health for different soil types and land uses. Further work is required to integrate new data sources and quality assure the work before publication is possible.

The indicator will use data currently being gathered on soil characteristics (physical, chemical, and biological) and land use to show how different soils are contributing to different ecosystem services as a measure of soil health.

National soil monitoring is currently being undertaken through the England Ecosystem Survey (EES) and the National Forest Inventory Plus (NFI+) within the terrestrial Natural Capital Ecosystem Assessment (tNCEA) programme. The tNCEA programme will provide valuable data for a better understanding of national soil health.

This report details the ongoing progress towards developing a national soil health indicator, including both the data collection and the work building upon the initial concept from the JNCC study and adapting it for a nationwide application.

The final indicator will be published once sufficient data have been collected through the tNCEA programme.

2. Progress to date

2.1. Data collection and analysis

2.1.1. Terrestrial Natural Capital and Ecosystem Assessment Programme

National soil monitoring is currently being undertaken within the terrestrial Natural Capital and Ecosystem Assessment (tNCEA) programme, yielding valuable new data to aid improved understanding of national soil condition. The tNCEA is supported by substantial new government investment, setting up long-term monitoring capability at a national/regional level. It will comprehensively assess the location, extent and condition of England's Natural Capital assets and track change over time. The current phase will complete two years of the five years needed for a soil health baseline. The next phase of capital investment, needed to complete the baseline by 2028, will be included in Defra's Research and Development (R&D) Spending Review.

2.1.2. England Ecosystem Survey

The England Ecosystem Survey (EES), a strategic field survey currently managed by Natural England, is a main data source of the tNCEA, measuring quality of natural capital assets and change in their condition over time. The EES will collect field data on land, landscape, soil, ecosystem processes, ecological communities, and some species. Field assessment and soil sampling procedures are conducted as part of the EES. Data are being collected on the soil type and on the physical, chemical, and biological soil properties across England's terrestrial ecosystems. This excludes woodlands, which are covered by the National Forest Inventory Plus (NFI+), another survey component of the tNCEA programme, managed by Forest Research. Soils data from the NFI+ will be incorporated into the finalised version of the E7 Soil Health indicator.

The EES monitoring plots are clustered within squares measuring 1 × 1 km (monads). Monads are aligned to the Ordnance Survey British National grid and selected via a stratified random sampling approach combined with use of inclusion probability weightings. Within each monad, there are up to six predetermined 1 ha squares (Landscape and Vegetation Plots) surrounding a 2 × 2 m 'Vegetation Plot'. The Landscape and Vegetation Plot is used to capture and report on habitat heterogeneity and complexity. Each Landscape and Vegetation Plot is overlaid at the centre by a 13 by 13 grid of 16 × 16 m squares, extending beyond the Landscape and Vegetation Plot. These 16 × 16 m squares are options for a 'Soil Plot', of which there are 169 options to choose from. One Soil Plot option is chosen per Landscape and Vegetation Plot, equating to up to six Soil Plots per monad. The default position for the Soil Plot is at the centre of the Landscape and Vegetation Plot. When conditions are unsuitable, an alternative option is chosen from the grid of Soil Plot options, following a standardised process.

Each Soil Plot is overlaid with 8 by 8 evenly distributed 1 m squares, with the centre four squares reserved undisturbed for the 2 × 2 m Vegetation Plot, in which plant species composition and broad habitat is recorded. The 60 remaining 1 m squares surrounding the Vegetation Plot are options for 'Soil Sampling Points'. Four Soil Sampling Points are chosen per Soil Plot; these are randomly selected, although the default position for the four sampling points is consistent across all Soil Plots. Adjustments to the default Soil Sampling Point locations are permitted if deemed unsuitable for soil sampling purposes, following a consistent approach. Soil data are generated from field and laboratory work as part of the EES.

Below (Section 2.1.3) is an extract of data collected during the first sampling year of the EES. This is an incomplete and pre-experimental dataset to be used as indicative of approach only. The data have been only partially cleaned and have only received provisional assurance from the tNCEA programme to be used for illustrative purposes.

2.1.3. Illustrative example of data

A reduced soil dataset for 67 monads (209 Soil Plots) was collated, including the number of earthworms, visual evaluation of soil structure (VESS), pH and estimated soil organic matter (SOM) content. Metadata, such as soil temperature, sampling location, and date of soil sampling was collected for each sampling point.

To assess the number of earthworms, a soil block measuring 20 × 20 × 20 cm at the south-east corner of each soil sampling point was dug out. After breaking up the soil along natural planes and fissures, earthworms were collected from within the soil block. The number of earthworms found at each soil sampling point was recorded and the total number of earthworms found per soil plot reported.

For the VESS, a block adjacent to the earthworm pit on the northern side was dug out, measuring 30 cm deep and the width of a spade. The soil structure of this block was visually assessed using the method developed by Ball *et al.* (2007). The VESS scores ranged from 1 to 5, with increments of 0.5 steps. The VESS score for the four soil sampling points within each soil plot was averaged.

Soil samples for organic matter and pH analysis were collected within each soil sampling point using a split corer with inner diameters of either 4.8 cm (standard) or 4.5 cm (core catcher). Sampling depth was standardized at 15 cm, and soil from the four soil sampling points was collected as a composite sample.

For SOM analysis, composite samples from the different soil plots were air-dried at temperatures less than 30 °C and passed through roller sieves smaller than 2 mm.

For the analysis of total carbon (TC), the sieved soil was ground to particles less than 0.5 mm. The TC content was determined through Dumas combustion at 1,200 °C coupled with Infrared Red (IR) spectrometry on 100–150 mg of ground soil. Total inorganic carbon (TIC) content was assessed by acidifying the sample with orthophosphoric acid and sparging it at 150 °C to liberate inorganic carbonates as carbon dioxide (CO_2). The resulting gas mixture, containing CO_2, was passed through the IR detector along with an oxygen carrier gas. Total organic carbon (TOC) was calculated by subtracting TIC from TC. In this instance, due to data unavailability, SOM was estimated from TOC content using the standard conversion factor of 1.72 which assumes that SOM contains 58% carbon (van Bemmelen, 1890).

The pH was measured on a soil volume of 10 ml of air-dried, sieved soil (less than 2 mm) in a 25 ml deionized water solution.

The reduced soil dataset was cleaned with errors in location (e.g. incorrect monad identified) and in each variable (e.g. SOM, Soil Texture, Earthworms and VESS) identified and corrected. A summary of the dataset was created showing minimum, median, mean, maximum, standard deviation, and number of samples for each variable within each broad habitat type. The broad habitats were recorded during the EES landscape and vegetation survey 2023 for each soil plot. The summary statistics were calculated in R (using the summary tools package), using the cleaned reduced soil dataset. The data ranges of this dataset are presented in Table 1.

To assure scientific quality, the summary statistics and method statement behind the data ranges were put through the tNCEA Defra Science Assurance process. This involved an internal review conducted by the Defra tNCEA team, followed by a working group review with representatives from Natural England and Environment Agency. Relevant components of the data's value chain were assessed, including data testing, quality assurance and independent data calibration. Following review, 'Provisional Assurance' was given, noting that the data is pre-experimental, and to be used as indicative of approach only.

Table 1. Data ranges (minimum (Min.) and maximum (Max.)) of estimated soil organic matter (SOM), visual evaluation of soil structure (VESS), earthworm count and pH for 67 monads (1 × 1 km squares) collected during the England Ecosystem Survey.

Broad habitat	SOM (%, estimated)		VESS (score)		Earthworm count (number of earthworms)		pH	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
Acid grassland	2.8	45.6	1	4.5	0	15	4	5.8
Arable and horticultural	1.4	15.3	1	4.5	0	36	5.6	8.4
Bog	22.2	81.5	1	4	0	8	3.5	4.4
Calcareous grassland	6.5	6.5	1	1.5	2	10	6.1	6.1
Dense scrub	13.9	13.9	1	1.5	2	11	5.6	5.6
Dwarf shrub heath	53.8	53.8	1	4	0	0	4	4
Fen, marsh and swamp	22.2	22.2	1	1	0	0	6.2	6.2
Improved grassland	2.1	70.2	1	5	0	76	4.5	7.7
Mosaic	15.3	24.8	1	2	0	8	3.8	4.9
Neutral grassland	2.8	44	1	5	0	34	4.8	6.9
Tall herbs	5.7	5.7	1.5	1.5	11	13	7.1	7.1

Note that this is an incomplete and pre-experimental dataset to be used as indicative of approach only. The data have been only partially cleaned and have only received provisional assurance from the tNCEA programme to be used for illustrative purposes. In this instance, due to data unavailability SOM (%) was estimated from Total Organic Carbon content using the standard conversion factor of 1.72 (van Bemmelen 1890).

2.2. Conceptual model development

The national indicator will use data such as those presented above as inputs to models that will help to put the data in context in order to understand the health of the soil.

In the original land parcel scale proof-of-concept study, JNCC produced a draft conceptual model for each ecosystem service that linked soil properties, environmental variables and land-use data to ecological processes and soils' contribution to the delivery of ecosystem services (Harris *et al*. 2023). The output was a dashboard visualisation that shows the current and potential delivery of multiple ecosystem services at a specific location. The conceptual models included soil and location variables such as soil texture and climate, land-use variables such as whether the land is arable, urban or woodland, and management-related variables such as the presence of cover or rotational cropping. An example of a conceptual model for climate regulation is included in Figure 1.

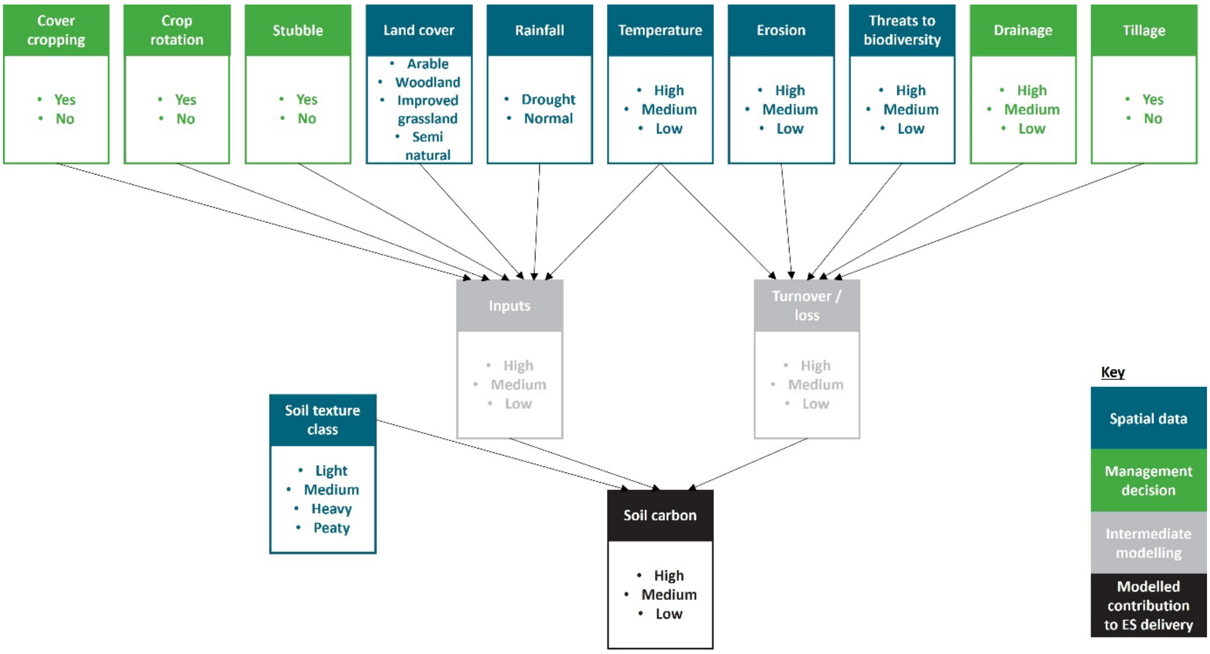

Figure 1. A diagram illustrating the conceptual model developed to understand soils' contribution to climate regulation through soil carbon storage.

For two of these conceptual models, full statistical models were developed, using a type of modelling called Bayesian Belief Networks (BBNs). A BBN can build on a conceptual model, by adding probabilities in a way that allows us to predict the potential outcomes of changing conditions within the system. This is helpful for understanding how management practices or environmental factors might impact the services provided by ecosystems (e.g. food production, water regulation).

The study aimed to show both actual and potential values of soil health in the results. Some factors relating to a soil's ability to deliver an ecosystem service are fixed (e.g. soil type), whilst others can change over time (e.g. management factors). It is therefore important for an indicator of 'health' to be contextualised and show the current state and the potential for improvement. For example, carbon storage in a peaty soil is likely to be higher than that of a sandy soil, even if it is in bad condition, due to inherent properties of these soil types.

Throughout financial year 2023-24, JNCC has continued work on the indicator, funded by Defra. This has included both the validation of the models that were developed and the adaptation of the concept for application at a national (England) level, rather than a land parcel level.

Two steps were taken to ensure the accuracy of the four ecosystem service models developed:

- **Literature Reviews:** An extensive review of scientific research was conducted to identify empirical evidence supporting each model. Existing studies were examined to confirm the validity, direction (positive or negative impact), and strength of connections between different factors within the models. Additionally, this review considered whether important factors were missing from the original models.
- **Expert Panel:** A group comprised of leading UK soil scientists from government and universities was convened. This group convened three times and provided additional feedback through surveys. Their focus mirrored the literature review: assessing the evidence for each model connection and suggesting improvements. Particular emphasis was placed on the models' adaptability for use as national indicators across the entire country.

The expert panel endorsed the concept and the fundamentals of the models, and provided valuable feedback that is being used to further refine the models. The literature reviews strengthened the evidence base for many existing relationships in the models, whilst suggesting additional variables and nuances. The 'maintenance of biodiversity' model is likely to see the most significant changes as a result of these reviews. The next step is to finalise the model variables and mathematical relationships based on the evidence gathered.

To adapt the models for use as a national indicator rather than a land parcel scale, the project team considered the modelling approach and the data sources available. The original study allowed users to input management options and local data for specific locations. The models would combine this information with spatial data for other factors in the model where these were available, to calculate predicted ecosystem service delivery at that point. A national indicator would instead need to be representative of England as a whole.

Whilst the models are likely to follow the same logic for a national and local indicator, the data inputs required differ significantly. A national-scale indicator will not be able to rely on local knowledge and management decisions to input into the model. It will require data that are applicable to the entire country, but the data do not need to be as detailed as in a land parcel scale indicator. Instead of knowing whether a certain management practice is taking place in a particular field, the national model needs to know what proportion of the country that management practice is taking place in.

Much of the work on this topic has therefore been around identifying and assessing potential data sources for these factors. Since the proof-of-concept study, data collection for the England Ecosystem Survey and for the National Forest Inventory Plus project have begun through the terrestrial Natural Capital Ecosystem Assessment Programme (tNCEA). These are collecting a range of data on soil from across the country, using a weighted random stratified sampling approach. The data collected are representative of non-urban soil across England.

This year, we also examined which aspects of these new data should replace data inputs that were used in the previous iteration. This was based on evidence from the literature reviews and expert panel mentioned above.

3. Next steps

The project team is in the process of finalising decisions based on the literature review and expert panel input, to create updated models. The next step is to adapt the code base to make use of new data inputs once they become available. We also plan to investigate the data sizes required before it will be possible to publish a final indicator baseline statistic. The expert panel advised of the need for the full EES dataset (being collected on a five-year cycle) before this is possible, with subsequent five-yearly updates. Interim statistics may be possible to produce ahead of this point.

Adapting the concept for a national scale will require new presentation and visualisation options. The concentric pie charts which were used in the proof-of-concept, comparing the local value, the average value across similar sites and the national average, will no longer be relevant. The project team has explored options and consulted the expert panel but plan further consultation on ease of interpretability before taking a final decision on how to present the results.

Once this work has been completed, a basic initial indicator will be published. However, further improvements are planned beyond that point to enhance the accuracy, sensitivity, and resolution of the models. This includes building out the probability tables associated with the models by disaggregating the land classes and soil texture classes. Good progress is being made towards producing a first iteration that can be used in wider consultation and built on.

The tNCEA is setting up long-term monitoring capability at a national/regional level, and up-to-date and comprehensive soils' data are a priority of the programme. The current phase of tNCEA is using capital investment to achieve two years of the five years needed for a soil health baseline, and provisional updates will be produced from 2024. The next phase of capital investment, needed to complete a national soil health baseline by 2028, will be included in Defra's R&D Spending Review.

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