NatureScot
Scotland's Nature Agency
Buidheann Nàdair na h-Alba

NatureScot

SCIENTIFIC ADVISORY COMMITTEE

Soil health and carbon budgets

Purpose

1. This paper briefs the Committee on soil health and soil carbon budgets. It considers how these concepts can be better integrated into land-use management practices to deliver nature-based solutions related to climate change.

Action

2. To ask the Committee:
   - to consider the significance of uncertainty attached to development and implementation of soil health and soil carbon accounting framework;
   - what the priority development areas for soil health and soil carbon budgeting by NatureScot should be?

Preparation of paper

3. This paper was prepared by Patricia Bruneau with input from Cecile Smith, Duncan Stone, Andrew Coupar and Tom McKenna. This paper is sponsored by Graham Neville.

Background

4. Following its Climate Emergency declaration in 2019, Scottish Government has developed a strong policy framework to support a Net Zero future. This framework recognises the role of nature in supporting a timely agenda for delivery: "*A healthy natural environment is key to achieving net zero. Evidence shows that areas which are nature-rich are also rich in carbon*"[1] and consequently rich in ecosystems benefits to society. The Climate Change Plan Update[2] focuses upon delivering a coordinated approach to reduction in emissions and acknowledges that: "…*our land* [is] *the cornerstone of our society and bedrock of Scotland's natural capital, but it has many uses. We have a finite amount of land and are making increasing demands upon it*".[3]

[1] https://www.gov.scot/publications/environment-strategy-scotland-vision-outcomes/ page 16
[2] https://www.gov.scot/publications/securing-green-recovery-path-net-zero-update-climate-change-plan-20182032/
[3] https://www.gov.scot/publications/securing-green-recovery-path-net-zero-update-climate-change-plan-20182032/ page 9

5. The interdependencies and benefits derived from healthy soils for the natural environment, the economy, and human well-being has become increasingly recognised as a pillar of sustainable use and management of natural resource.

6. Soils play a major part in many Nature-Based Solutions (NbS) for mitigating impacts of, and adapting to, climate change. Soils have many functions, they obviously support food and biomass production, contribute to the regulation of water flow and water quality, and the geochemical cycling of nutrients. They provide a platform for buildings and development. Soils are also valuable natural assets and part of the fabric of our landscape and cultural heritage. Soils are a critical habitat and their importance for above- and below-ground biodiversity is increasingly recognised. Furthermore, soils are the largest natural terrestrial component of the carbon cycle such that their management offers opportunities and risks for controlling carbon pools (soil carbon stock) and fluxes (soil GHG emissions).

7. Despite soils being a key natural asset, there is still no primary legislation for the protection of soils in Scotland (see annex 1). However, soil protection and management is a feature of a range of policies. This includes: environmental protection (such as habitat, biodiversity, landscape, heritage protection, etc.), water, climate change, pollution, waste, land use & planning and land ownership. Such a piecemeal approach to soil protection and management policy can create inconsistency in setting overall policy objectives and can lead to conflicting delivery mechanisms. This may be detrimental to long-term conservation objectives despite delivering a short-term economic or environmental gain. This issue is further confounded by the spatial and temporal variability in soil functions seen across Scotland. In practice, this means that 'one model fits-all' representations of soil behaviour are clearly inadequate.

Definitions

8. Soil health and soil carbon budget are commonly defined as follows:
    - The concept of soil health (sometimes described as 'soil quality') is a field of considerable interest which evolved from the recognition that soils play a vital role in controlling and supporting Earth's ecosystem. Soil health can be defined as the continued capacity of soils to support ecosystem goods and services. Enhancing good soil health and combating soil degradation (aka the drivers and mechanisms of bad soil health) underpins most of the UN Sustainable Development Goals[4].
    - Soil health is a paradigm used to quantify and monitor a more holistic representation of soils as ecosystem services providers. One of the key properties of soils is their ability to help regulate climate by controlling exchange of gases through the atmosphere, controlling rates of soil organic carbon sequestration and providing a stable repository for carbon below ground.
    - Soil carbon comprises organic carbon, inorganic carbon and carbon associated with living plant roots and soil animals. Natural processes in soils control the flux of carbon between terrestrial (i.e. biosphere), atmospheric and water environmental compartments.

[4] https://sdgs.un.org/goals

- Soil carbon budget refers to the balance of the fluxes between various pools of carbon. These fluxes operate at different temporal and spatial scales.
- Soils are open-systems in that they may permanently gain or lose carbon and are responding to changes in external environmental parameters. Soils can be damaged very rapidly but take many take centuries to recover their lost functionality.

Overview of current evidence

9. Recent R&D in Scotland for the development of soil and environmental monitoring frameworks[5,6,7] have considered the practical issues relating to defining soil health and the implications for data collection[8,9,10]. Metrics for assessing the state of natural capital assets and ecosystem services are not currently readily available for all soil functions. However, soil organic carbon content is acknowledged as a good indicator of multiple soil functions. There is a strong base of existing data[11,12], modelling and apps[13],[14] providing broad-range information on the distribution of soil organic carbon for different soil types, land uses and habitat types across Scotland[15,16]. These data provide a robust snapshot of the soil carbon store. Despite this, direct measurement of rate of change in soil organic matter remains difficult. Although R&D is providing a clearer picture of the status and processes driving soil functionality and has promoted a better appreciation of risks to soils from changing climates, significant knowledge gaps remain in understanding the relationship between soil carbon and changes in habitat conditions.

10. Though there is a growing understanding and access to good evidence on the distribution of soil carbon and of the individual GHG fluxes for a range of habitats and land use (both national and local scales), we need to push now for climate solutions that are also beneficial for biodiversity; we recognise[17] that we cannot wait to have all the evidence to act and we will have to work around evidence gaps. There is also the larger uncertainty emerging from climate change, and effects on habitats.

Carbon tools

11. Numerous carbon audit tools (see annex 2) are now available to quantify the whole carbon footprint of an activity by identifying sources and sinks related to GHG emissions. These tools are increasingly used to demonstrate GHG reduction achievements, whether

[5] https://soils.environment.gov.scot/soils-in-scotland/soil-monitoring/
[6] https://www.climatexchange.org.uk/research/projects/measuring-the-vulnerability-of-scottish-soils-to-a-changing-climate/
[7] https://www.gov.scot/publications/environment-strategy-scotland-vision-outcomes/
[8] Bunemann, E. K. et al (2018) *Soil quality – a critical review*. Soil Biology and Biochemistry https://www.sciencedirect.com/science/article/pii/S0038071718300294
[9] Sharman, M. (2017) *Soil health: evidence review*. A Working paper by the Cambridge Institute for Sustainability Leadership. https://www.cisl.cam.ac.uk/resources/publication-pdfs/soil-health-summary-report.pdf
[10] Stewart, R.D. et al (2018) *What we talk about when we talk about soil health,* In: Agriculture and Environmental Letters https://dl.sciencesocieties.org/publications/ael/abstracts/3/1/180033
[11] Scotland's soil datahub. https://soils.environment.gov.scot/maps/
[12] https://www.hutton.ac.uk/learning/soilshutton/digital-soils/statistics
[13] Aitkenhead 2016 Mapping peat in Scotland with remote sensing and site characteristics https://onlinelibrary.wiley.com/doi/abs/10.1111/ejss.12393
[14] NS bare peat app https://www.arcgis.com/apps/webappviewer/index.html?id=961b594d4ea3413aa171036f0ebe47f8&extent=-1993913.4584%2C7354813.1225%2C1528304.805%2C8756362.4731%2C102100
[15] https://www.climatexchange.org.uk/research/projects/soil-carbon-and-land-use-in-scotland/ (2018)
[16] https://sefari.scot/research/assessing-natural-capital-impacts-and-dependencies-within-upland-farming-systems
[17] https://www.gov.scot/publications/securing-green-recovery-path-net-zero-update-climate-change-plan-20182032/

for use by private sector actors, or for policy purposes (such as future rural support). This, in turn, may boost green credentials for activities ranging from renewable industries to farm businesses. These tools can also define options to reduce, mitigate or offset GHG emissions. 'Carbon accounting' as opposed to 'carbon management' is becoming the primary metric for assessing and reporting on effectiveness of GHG emission intervention(s) across industry sectors. However, discrepancies remain on how much consideration is given to the soil carbon stock and soil carbon fluxes. Typically when included in these tools only average values of soil carbon are used instead of using site- or region-specific measurements.

12. Carbon audit tools can be used to identify and quantify the positive carbon flux budgets that have become central to many NbS addressing Climate Change. There are some nature-based certified, voluntary standards and other protocols for the reduction of carbon emissions (e.g. Woodland Carbon Code). These allow management of carbon offset portfolios, which may also unlock co-benefits (global food supply, biodiversity gain), though not necessarily. The opportunities to attract private finance towards the implementation of nature-based solutions will partly depend on reliable accounting of benefits derived (whether carbon sequestration, water quality, flood risk reduction, biodiversity etc.).

Timeline of carbon sequestration

13. The way the land is managed will be critical to reach the Net Zero target[18]. Active management of the land can lead to sequestration, or temporary or permanent loss of existing stocks in multiple compartments of the environment. For example, cultivated soils which may have lower carbon content than the same soil under semi-natural conditions offer the opportunity to sequester carbon through changes in practices, and it is speculated that a change in agricultural management towards more agroecological approaches could help sequester significant amounts of carbon cumulatively as part of yearly crop rotation cycles. An issue in agriculture though is reversibility, whereby soils may be disturbed again thereby releasing part of the carbon store. In permanent pastures, there should be potential to increase carbon stores, though at some point, equilibrium will be reached.

14. Other sectoral reductions in GHG emissions, however important to achieve promptly, will not be enough to deliver Net Zero. Because of the risk of climate overshoot[19], significant changes to the way the land is managed need to be implemented in the next 10 years. Related to that is the timing issue of 'spending' soil carbon now to 'earn' new carbon sequestration in biomass or peat in 50 years' time or 100+ years' time (for example for commercial forestry, or planting native woodlands in peat and other carbon-rich soils).

Conclusions

15. The inclusion of soil health and soil carbon budgets in NbS needs to address fundamental issues that cross between R&D and policy. Understanding the uncertainty

[18] https://www.gov.scot/publications/securing-green-recovery-path-net-zero-update-climate-change-plan-20182032/
[19] Climate overshoot: period of time in which warming is increasing past the 1.5°C mark and then cooling back down

associated around timescales of interventions, and evaluation of their outcomes, will be critical. Issues related to trade-offs and costs/benefits to nature are also time sensitive.

16. The time to influence land-use policy, as well as directing private finance towards restoring nature, is now; even if we know this is an imperfect model. We can build on existing tools that allow for easier and practical assessment of the status and changes to soil health, albeit within some level of uncertainty. Working to address these issues will require appropriate engagement with partners who may have different priorities regarding carbon budgeting (see annex 3). Issues of interest include:
    - the definition of a 'correct' timescale(s) for NbS interventions and for the evaluation of their outcomes when considering soil carbon budgets;
    - the balancing of short-term losses in soil health and soil carbon vs long-term benefits towards emission reduction and carbon sequestration;
    - the impacts of offsets and emissions trading schemes on soil health;
    - markets reluctance to account for 'hard to value' natural components;
    - the future-proofing of current interventions to minimise the risk of unintended consequences; and,
    - addressing remaining evidence gaps to assess changes in all soil and terrestrial ecosystems in Scotland.

17. Opportunities may also arise from improving soil health. These include:
    - data-mining and emergence of new modelling and surveillance technology to explore the spatial and temporal variability of environmental processes; and,
    - co-benefits gained through addressing the twin challenges of climate change and biodiversity losses.

Questions to the Scientific Advisory Committee

We are asking the Committee to consider how, given uncertainty attached to the evaluation of soil health and soil carbon budget in Scotland, NatureScot could:

(i) develop robust and informed approaches, that minimise the risk of failure, to protect and enhance healthy soils for securing both carbon and biodiversity benefits as an outcome.

(ii) demonstrate the effectiveness or risk associated with NbS when engaging government and partner organisations who may have different policy priorities that conflict with our own.

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SAC paper
Annex 1: Soil Policies and Soils facts and figures for Scotland

Soil policy in Scotland

Despite soils being a key natural asset, there is still no primary legislation for the protection of soils in Scotland[20]. The 2009 Scottish Soil Framework[21] which aligned earlier work on the development of the EU Soil thematic strategy[22] promotes a vision with: "*soils recognised as a vital part of our economy, environment and heritage, to be safeguarded for existing and future generations in Scotland*" and aims to "*promote the sustainable management and protection of soils consistent with the economic, social and environmental needs of Scotland*". Despite no primary soil protection legislation, soil protection and management is a feature of a range of policy. This includes environmental protection (such as habitat, biodiversity, landscape, heritage protection, etc.), water, climate change, pollution, waste, land use and planning, and land ownership. Soils may not be directly mentioned in the primary legislation related to these topics, but appear in most supporting 'instruments' for delivery.

Although no body of soil in Scotland has been designated solely for its intrinsic conservation value, soil-use and management narratives are at the centre of many of NatureScot operations and are critical to promote the sustainable use of Scotland's natural heritage as a whole. Consideration is given to healthy soil function and minimising threat to soils in many sites designation statements. Working alongside other public bodies, NatureScot implements a range of related policy: Scottish Biodiversity Strategy, National Planning Framework, Land Use Strategy, Climate Change Policy. These all contribute to soil protection. As statutory consultees in EIA and SEA, NatureScot staff routinely assess impacts of proposed land-use activities on soil health when it impacts on wider biodiversity and geodiversity conservation issues. NatureScot also plays a leading role in shaping national soil R&D agenda to suit our evidence requirements. We demonstrably and successfully promote awareness of soil and promote access to soil guidance and digital information (Scotland's Soil Website[23]) in Scotland in partnership with other agencies. Our leading role in protecting carbon-rich soils (Scottish Planning Policy and Carbon and Peatland map) and restoration of peatland (Peatland Action Programme) is well established.

Soil carbon and natural capital in Scotland

Total biocarbon stock (land-based plants, soils, animals and ecosystems as a whole) was estimated at 4,266 MtC in UK in 2007 with most of it (94.2%) held in soils[24]. Scotland's soils, which are generally in good condition[25], hold over 3000 MtC of which $^2/_3$ is held in Scotland's peatlands. Healthy peatlands have the potential to sequester carbon at a rate of 0.7 to 2.8 tCO_2e per hectare per year[26]. However, due to the extent of peatland degradation,

[20] https://www.climatexchange.org.uk/media/3232/soil-governance-in-scotland.pdf
[21] https://www.gov.scot/publications/scottish-soil-framework/
[22] https://ec.europa.eu/environment/soil/three_en.htm - to note included a proposal for a EU Framework Directive which has since lapsed.
[23] https://soils.environment.gov.scot/
[24] https://www.gov.uk/government/publications/a-natural-capital-approach-to-attaining-net-zero-nature-based-interventions
[25] https://soils.environment.gov.scot/soils-in-scotland/state-of-scotlands-soils/
[26] https://www.nature.scot/snh-commissioned-report-562-managing-and-restoring-blanket-bog-benefit-biodiversity-and-carbon

Scotland's peatlands, as a whole, are net emitters of up to 9.7 $MtCO_2e$ per year[27,28]. Scottish woodlands currently remove about 5.4$MtCO_2e$ per year (based on 2018 data)[29] with 75% of carbon store held in soils (to 1m depth)[30].

The land use, land use change and forestry sector (LULUCF) captures carbon removals and GHG emissions from the use, and change in use, of different land types in the UK. The main land categories are forestry, crop-land, grassland, wetlands and settlements. Under the current methodology of the Greenhouse Gas Inventory, the LULUCF sector is a net carbon sink[31]. The sector sequestered 10.3 $MtCO_2e$ in 2018, which is equivalent to abating 2% of UK emissions[32].

Scotland's Natural Capital[33] is worth at least £196bn, supporting 240,000 jobs[34]. Much of this value is generated by the nature and landscapes that underpin our economic competitive advantage with growth sectors including tourism, renewable energy and food and drink heavily dependent on a high-quality natural environment. Investing in natural capital and nature-based solutions can drive inclusive economic development and investing in global soil carbon and soil health is increasingly as presenting opportunities to increase resilience in food supply chains and achieve climate targets in hard-to-abate activity sectors.

Nature-Based Solutions (NbS)

In Scotland, commitments towards development of Nature based Solutions are increasingly considering evidence and metrics that assess soil health and sustainable use of soils. This applies across a range of sectoral interests (i.e. not limited to agriculture and forestry sector and water quality issues). As NbS deliver multiple benefits, they can help to fix many societal problems[35], and can be the most cost-effective way of generating economic activity that will make our communities sustainable and more resilient. However, tailored approaches to soil health and soil carbon accounting in NbS is likely to be required across different land-use sectors in order to reflect the difference in assets and services provided by soils.

[27] https://www.theccc.org.uk/publication/net-zero-the-uks-contribution-to-stopping-global-warming/
[28] http://www.parliament.scot/ResearchBriefingsAndFactsheets/S4/SB_12-28.pdf
[29] Scottish greenhouse gas emissions 2017 (2019). The Scottish Government, Edinburgh. https://www.gov.scot/publications/scottish-greenhouse-gas-emissions-2017/
[30] Forestry Statistics 2019 https://www.forestresearch.gov.uk/tools-and-resources/statistics/forestry-statistics/..
[31] BEIS (2020) Provisional UK greenhouse gas emissions national statistics 2019. The Global Warming Potential for methane and nitrous oxide used in the current GHG Inventory is based on the IPCC's 2007 Fourth Assessment Report (AR4).
[32] https://www.theccc.org.uk/publication/sixth-carbon-budget/
[33] https://www.ons.gov.uk/economy/environmentalaccounts/articles/scottishnaturalcapitalaccounts/2020
[34] Valuing our Environment – the economic impact of Scotland's natural environment, SNH, 2008
[35] They can be applied to physical and mental health, flood management, urban environmental quality e.g. air quality and cooling, asorbing and storing greenhouse gases, and managing pests, diseases and pathogens

SAC paper
Annex 2. Tools and verification protocols for carbon budgets

Natural capital accounting

Soils as key natural assets have both inherent and manageable properties which can be valued. The manageable properties (such as carbon sequestration) can be improved to increase the value of the asset and be included in natural capital accounting. Within the ecosystem service (ES) and natural capital (NC) approach these values are usually accounted for as part of the Cultural ecosystem services value – i.e. values that are derived by humans, generally without extracting or placing a strain on the environments themselves, these benefits often occur within our own consciousness. However, accounting for costs incurred dues to losses, degradation or restoration of the assets now and to future generations is considered differently under an ES or NC approach. The value of Natural Capital is in the natural asset and its ability to provide benefits now and into the future. The ES approach just considers those benefits flowing from an asset now. The NC and ES approaches both take into account economic (market) and non-economic (social and environmental) benefits to provide a fuller and more true overall value.

Natural Capital accounting can provide a framework for integrating assessment of soil functionality. The Net zero Plan seeks *'achieving a balance between the greenhouse gases put into the atmosphere and those taken out. What we do in the next decade to limit emissions will be critical to the future, which is why every country, sector, industry and each one of us must work together to find ways to cut the carbon we produce*'. It requires '*understanding our impact on the planet, agreeing the boundaries of our carbon accounting, our ambitions and devising a robust and informed strategy for action'.* [36]

Natural Capital Assessment Indicators

In England the Natural Capital Committee's (NCC) recommendations for using nature based interventions to reach net zero greenhouse gas (GHG) emissions by 2050 recognised that delivery of net zero will become incredibly difficult, if not impossible, without environmental net gain. This requires '*improving the natural capital system modelling capability, including the full range of ecosystem services and assessing the carbon lifecycle of any approach. Designing interventions on the basis of least cost and without undertaking robust system wide scenario analysis is likely to result in perverse outcomes including increased GHG emissions.'* [37]

The Natural Capital Asset Index (NCAI)[38] was launched in 2011. Scotland became the first country in the world to publish a detailed attempt to monitor annual changes in natural capital. It includes indicators for carbon store, but not for fluxes in soil carbon.

[36] https://www.climatexchange.org.uk/research/projects/climate-change-natural-capital-and-adaptation-in-scotland-s-marginal-lands/
[37] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/879797/ncc-nature-based-interventions.pdf
[38] https://www.gov.scot/publications/scottish-natural-capital-ecosystem-service-accounts-2019/

Windfarm carbon calculator

The windfarm carbon calculator's purpose is to assess, in a comprehensive and consistent way, the carbon impact of wind farm developments. This is done by comparing the carbon costs of a wind farm development with carbon savings over the duration of its operation. The tool considers the changes to carbon store in peatland soils.

Peatland Code

- Peatland Code emissions reduction accounts for both GHG from, and sequestered by, peatland. It does not account for carbon stored within the peatland or carbon saved when substituting peat products for products with a lower carbon footprint.
- The Peatland Code was published in 2017. It is operated by the IUCN UK Peatland Programme and DEFRA are involved as it is a UK initiative.
- It is a voluntary certification standard for UK peatland projects wishing to market the carbon benefits of peatland restoration. It provides assurance that the carbon benefits being sold are real, quantifiable, additional and permanent.
- There is a significant appetite (in the hundreds of £millions) from private investors to fund peatland restoration in return for carbon credits but there are barriers to be overcome to unlock this. The Code is the main mechanism to attract this investment, however there are few examples of that happening yet in Scotland (or in the wider UK) and the carbon market is still immature.
- A small number of projects have been validated and others are going through the approval process, listed on the peatland code registry. Only two projects in Scotland have so far (Dec 2020) been verified with more than ten 'under development' on the register, and many more potential projects being developed.

Woodland carbon code

- The Woodland Carbon Code does consider the soil carbon pools, but unless a specific soil carbon assessment was conducted prior to tree planting, the soil carbon content at the site at the start of the project will be estimated from national average values for the nearest broad land-use and soil type combination. Changes to the soil carbon pools will be estimated from standard rates of soil disturbance associated with a range of forest management practices.
- The Woodland Carbon Code is the voluntary standard for UK woodland creation projects.
- Independent validation and verification to this standard provides assurance and clarity about the carbon savings of these sustainably managed woodlands.
- The UK Woodland Carbon Code is managed by Scottish Forestry. Prior to April 2019 it was managed by the Forestry Commission.

The Woodland Carbon Guarantee (available in England only)

- The Woodland Carbon Guarantee is a £50 million scheme that aims to help accelerate woodland planting rates and develop the domestic market for woodland carbon for the permanent removal of carbon dioxide from the atmosphere. It is an objective in the 25 Year Environment Plan and was announced in the autumn 2018 Budget.
- The Woodland Carbon Guarantee provides the option to sell captured carbon in the form of verified carbon credits, called Woodland Carbon Units (WCUs), to the government for a guaranteed price every 5 or 10 years up to 2055/56.
- The Guarantee is not part of the woodland carbon code, but all projects under the guarantee must conform with the code. There are no plans for a similar approach in Scotland at this stage.

SAC Carbon Audit – AgreCalc

- Agrecalc was developed by SAC Consulting – part of SRUC, in response to the growing need for a simple-to-use, accurate and science-driven carbon audit tool.
- In 2020, a carbon footprint tool, which aims to help farmers reduce their greenhouse gas emissions, has been updated to include a soil sequestration module.

SAC paper
Annex 3 Managing uncertainty – examples of challenges

Can NatureScot define a 'correct' time scale for intervention and evaluation of outcomes that aligns with other partners consideration on the issues?

Accounting frameworks that consider soil carbon stores alongside other environmental carbon stores should consider payback time for carbon benefits over appropriate timescales. Since all ecosystems give off CO_2 through respiration, varying daily and seasonally, key judgements are required on the period of time to consider these changes; and, whether emissions are 'more' (a liability) or 'less' (an asset) than expected.

Defining a 'correct' timescale is likely to be closely related to the time scale of the land-based activities (aka payback time for windfarm, lifecycle of tree or crop rotation, habitat recovery climax) but also to the prospected policy outcomes that the activities is intended to support.

Development on peatland soils is usually not supported through national planning policy, as the short loss of the carbon asset from activities may need decades or more to be compensated by the development's outcomes. The trade-offs, restoration plans and mitigation measures attached to planning consents all may operate at different timescales than the development itself.

How to weight short-term soil carbon cost vs long-term Climate Change emission targets in our current approach to NBS.

A particular dimension of soil carbon sequestration/storage in agriculture soils is that it can be more easily reversible and non-permanent (due to changes in practices) than for other longer term uses such as forestry. This leads to a particular issue of valuing the long term benefits of storing soil carbon, since carbon sequestration in managed systems occurs only as long as the beneficial land management practices are maintained and these practices remain relevant.

Can we future-proof interventions?

How can we translate our understanding of the feedback loops involved in soil health to understand the impacts of climate change and changed land use/ land management practices (i.e. changes in soil properties, risks and functions) and to help future-proof NatureScot's work? This may need new internal skills and capacity to evaluate impacts of soil carbon change. Recent work on afforestation targets[39],[40] has shown issues when applying area-based targets that do not fully account for local site characteristics.

[39] Matthews et al 2020 - Not seeing the carbon for the trees? Why area-based targets for establishing new woodlands can limit or underplay their climate change mitigation benefits
https://www.sciencedirect.com/science/article/pii/S0264837719304041?via%3Dihub
[40] Friggens et al 2020 - Tree planting in organic soils does not result in net carbon sequestration on decadal timescales
https://onlinelibrary.wiley.com/doi/full/10.1111/gcb.15229

How can we add value to the current soil evidence-base to support NbS?

How can we promote the creation/restoration of habitats as nature-based solutions for which evidence on climate benefits is insufficient or show limited present-day benefits? Similarly, if we continue to improve our valuations based on monetised carbon tCO_2e credits, are we in danger of squeezing out more intangible nature components (biodiversity, landscapes) simply because they are harder to measure? How do we address this?

In Scotland, land use policy measures that directly finance greenhouse gas mitigation have been limited to agri-environment climate and forestry schemes within the Scottish Rural Development Programme (SRDP), part of Pillar 2 of the CAP, and peatland restoration.

Land-use change, notably through peat restoration and woodland planting / regeneration, but also potentially through changes in the management of moorland, grassland and arable land, could enhance carbon sequestration. Accounting for both the carbon stock and flux in soil present uniquely difficult challenges for establishing a baseline, monitoring, reporting and verification of schemes.

What are the evidence gaps?

We need better knowledge of the soils spatial constraints that should influence decision-making process in selected Nature-based Solutions especially when assessing the time scale of likely net source of greenhouse gases versus sequestration following a land management intervention. Data-mining of existing evidence and assessing knowledge and gaps to cover all Scottish soils and all terrestrial natural systems / exploring R&D opportunities for spatial heterogeneity of soils requires a balance between soil survey vs soil modelling approaches.

Much uncertainty remains about other carbon-rich habitats (upland moorland, some coastal and grassland systems). We are still seeking to refine our understanding through our own projects and others for specific habitat types and land use.