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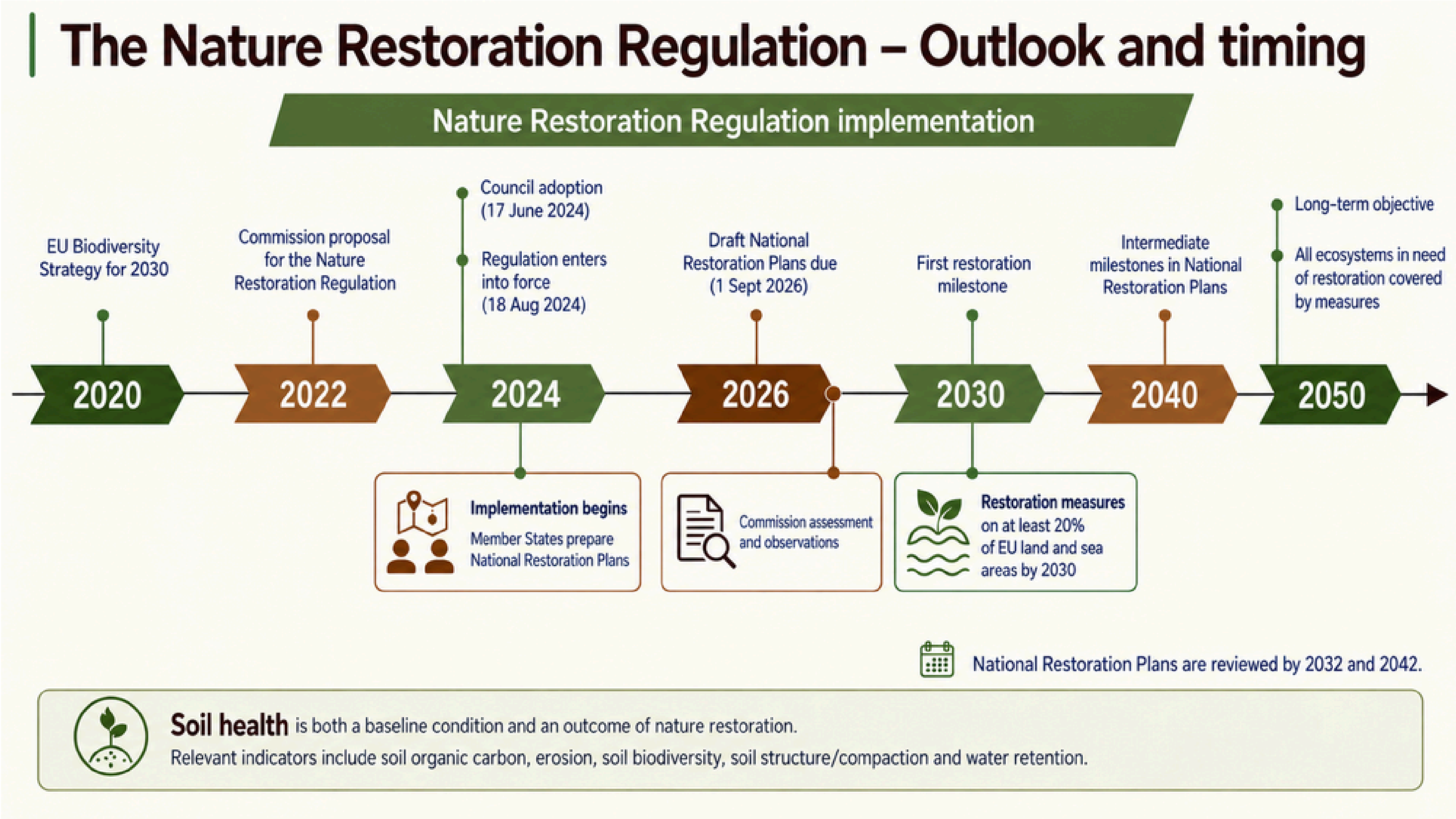
AI 4 Soil Health

DIALOGUE 1 Soil Health and Nature Restoration: Governance, Methods & Data

Nature Restoration Regulation: Why it matters for soil health

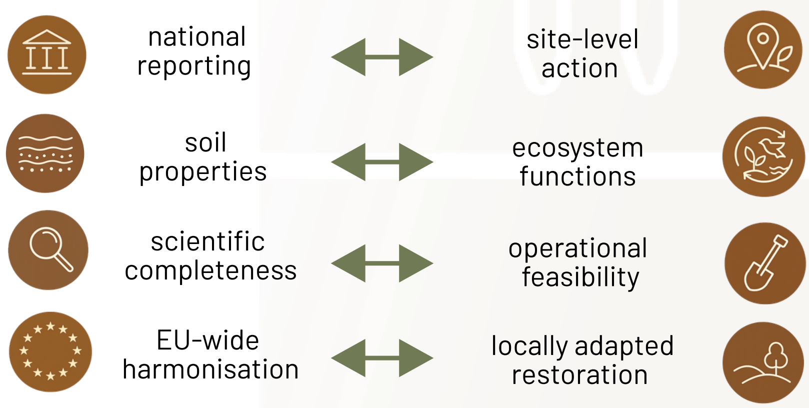


Key takeaways and recommendations from Dialogue 1

The first AI4SoilHealth Cross-Policy Soil Dialogue examined how the Nature Restoration Regulation and the Soil Monitoring Law can work together in practice. While the Soil Monitoring Law can strengthen diagnosis of soil condition and degradation, the Nature Restoration Regulation creates restoration targets, planning duties and implementation requirements. Coherence depends on whether monitoring results can be translated into restoration priorities, management choices and adaptive action at the right territorial scale.

The dialogue brought together complementary perspectives from **Eleonora Peruzzi (CNR-IRET)** on soil health and nature-based solutions, **Vito Emanuele Cambria (BiodivRestore Knowledge Hub and RIRE)** on National Restoration Plans and governance, **Christine Alewell (University of Basel)** on quantitative soil-health assessment through SHERPA, and **Vince Chukwu (University of Aberdeen)** on peatland forest management and soil-carbon modelling.

Across these perspectives, the webinar highlighted four recurring tensions.



Soil organic carbon emerged as an important bridge across policies, but credible implementation also requires evidence on hydrology, erosion, nutrients, structure, contamination and biological functioning.

Key Takeaways

Soil condition is both a baseline constraint and a restoration outcome: degraded soils can limit interventions, while restoration can rebuild soil functions.
Indicators must answer a defined implementation question; EU reporting and site-level management require different but connected evidence.
Soil organic carbon is a useful cross-policy bridge, but it is not a complete proxy for integrated soil health.
Diagnosis and projection are complementary: SHERPA assesses current pressures, while ECOSSE explores long-term management effects.
Governance determines whether evidence changes practice: data sharing, clear responsibilities, participation and adaptive decision rules are essential.

The Nature Restoration Regulation creates a substantial demand for soil evidence, although soil-health requirements are distributed across different ecosystem provisions. Soil organic carbon is explicitly included among the available agricultural and forest indicators, while drained peatlands under agricultural use are subject to quantified restoration and rewetting obligations.

The dialogue showed that carbon alone is not sufficient to assess soil health or restoration success. Soil structure, hydrology, nutrient pressures, erosion and biological functions also need to be considered. It also highlighted the difference between indicators used for national reporting and the finer-scale information required to design measures at field, habitat, forest, landscape or hydrological-unit level.

Building on the inputs from the NRR, the Soil Monitoring Law can provide a wider assessment framework, while the AI4SoilHealth project can contribute through the elaboration of question-led indicator selection, integrated soil-health assessment, field measurements, remote sensing, modelling and transparent aggregation across scales. The practical value of these tools will depend on whether monitoring results are linked to clear management responses, advisory support and adaptive governance.

Policy Recommendations

Make soil-health conditions and constraints explicit in National Restoration Plans.
Combine implementation indicators, such as area restored, with indicators of soil condition and ecosystem function.
Select indicators according to the policy question, territorial scale, reporting unit and required action.
Connect national trend reporting with field, soil-unit, habitat, landscape and hydrological information.
Align Nature Restoration Regulation and Soil Monitoring Law data systems to avoid parallel monitoring architectures.
Strengthen coordination among authorities responsible for nature, agriculture, forests, soil, climate and water.
Clearly distinguish peer-reviewed evidence, preliminary research, modelling results and expert opinion.
Use adaptive management so that unsatisfactory trends lead to review and adjustment of restoration measures.

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AI 4 Soil Health

DIALOGUE 1 Soil Health and Nature Restoration: Governance, Methods & Data

Opening & Framing

ISINNOVA

ISINNOVA research innovation sustainability

"How can soil information move from diagnosis and monitoring to restoration planning and the implementation of sustainable management practices?"

The dialogue opened by positioning the first AI4SoilHealth Cross-Policy Soil Dialogue at the **intersection of soil monitoring and nature restoration.** The Soil Monitoring Law and the Nature Restoration Regulation were presented as complementary policy frameworks: the former strengthens the basis for assessing and monitoring soil condition, while the latter translates environmental ambitions into restoration objectives, national planning requirements and ecosystem-specific action.

Against this backdrop, the dialogue was structured around a **central science-for-policy question**: *How can soil information move from diagnosis and monitoring to restoration planning and the implementation of sustainable management practices?* This perspective provided the conceptual thread for the discussion, connecting questions about baselines, indicators and territorial scale with governance, nature-based solutions, and the monitoring of peatland and forest carbon.

The dialogue brought together different scientific and policy outlooks to explore these connections and the practical challenges of turning soil evidence into action.

Scan the QR code or cleck here to watch the full webinar and listen to the complete contributions from the speakers.

AI4SoilHealth Cross-Policy Soil Dialogues

DIALOGUE 1 **SOIL HEALTH AND NATURE RESTORATION: GOVERNANCE, METHODS & DATA**

Dr. Eleonora Peruzzi

CNR-IRET, Pisa Researcher in Soil Health and Nature-based Solutions

Dr. Vito Emanuele Cambria

Sapienza Università di Roma & BiodivRestore Knowledge Hub

Prof. Christine Alewell

University of Basel, Professor of Environmental Geosciences

Dr. Vince Chukwu

University of Aberdeen, Environmental Modelling Group

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AI 4 Soil Health

DIALOGUE 1 Soil Health and Nature Restoration: Governance, Methods & Data

Policy & Governance

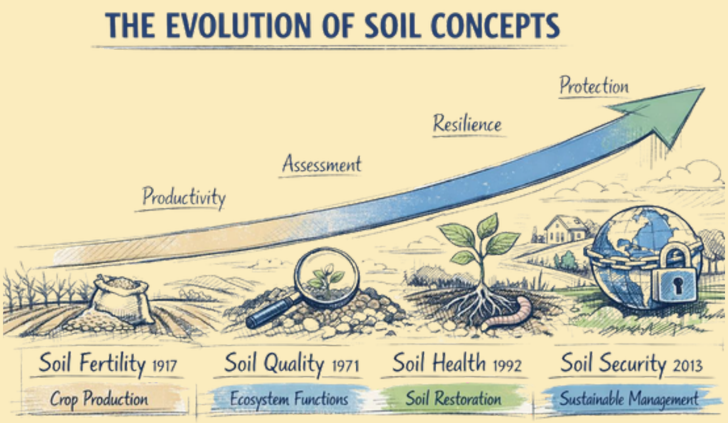
Soil health and nature-based solutions

Eleonora Peruzzi | CNR-IRET

CNR IRET Istituto di Ricerca sugli Ecosistemi Terrestri

Soil is the foundation of nature-based solutions' effectiveness.

Eleonora Peruzzi argued that **soil health is a precondition for the effectiveness of many nature-based solutions**. Nature-based solutions seek to protect, restore and manage ecosystems while addressing climate, biodiversity and wider societal challenges. Their effectiveness depends heavily on soil-mediated processes, including carbon storage, nutrient cycling, water regulation and support for biodiversity.



She described a gradual shift in soil science and policy from a narrow focus on fertility and productivity towards a broader understanding of soil functions, resilience and ecosystem services. **Soil is increasingly recognised as a living and active system rather than a passive substrate.** Monitoring systems, however, have not fully followed this conceptual evolution. They remain fragmented, incompletely harmonised and only weakly connected to the evaluation of nature-based solutions.

Peruzzi identified **soil monitoring as a major bottleneck**. Physical and chemical indicators are more established, while biological indicators have historically been underrepresented. Recent developments include microbial biomass, enzyme activity, molecular techniques, remote sensing and AI-supported digital soil mapping. However, comparable and operational protocols are still limited.

A central point was the **bidirectional relationship between soil and nature-based solutions**. Healthy soil supports the effectiveness of restoration interventions, while well-designed nature-based solutions can protect soil, prevent degradation and improve its physical, chemical and biological condition. This means that monitoring should not focus only on whether a measure has been implemented, but also on whether soil condition and ecosystem functions have improved.

Peruzzi's presentation also highlighted the **growing convergence between the Nature Restoration Regulation and the Soil Monitoring Law**. The Nature Restoration Regulation includes soil organic carbon among the indicators available for agricultural and forest ecosystems, while the Soil Monitoring Law establishes a broader framework for monitoring the physical, chemical and biological dimensions of soil health.

Important gaps nevertheless remain. **Biological indicators are still underrepresented**, methodologies are not sufficiently harmonised, and indicators are not always clearly linked to soil functions and ecosystem services. Peruzzi therefore stressed the need for a minimum but flexible set of indicators that can be adapted to different pedoclimatic and land-use contexts.

Her main conclusion was that **soil indicators are not merely technical tools**. They form a bridge between soil science, the evaluation of nature-based solutions and the implementation of EU restoration policy. Indicators should therefore be harmonised, function-based and aware of biodiversity.

Why is the Nature restoration Law important for soil health?

- Creates a stronger policy need for effective, harmonised soil monitoring
- Makes soil health part of ecosystem restoration
- Links restoration to measurable soil indicators
- Targets soil carbon and drained peatland restoration
- Connects healthy soils with biodiversity, climate resilience and ecosystem functions

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AI 4 Soil Health

DIALOGUE 1 Soil Health and Nature Restoration: Governance, Methods & Data

Policy & Governance

From research to National Restoration Plans

Vito Emanuele Cambria | BiodivRestore Knowledge Hub and RIRE

Restoration is a team sport!

Vito Emanuele Cambria presented two complementary networks supporting implementation of the Nature Restoration Regulation during the critical phase in which Member States are preparing their National Restoration Plans: the pan-European **BiodivRestore Knowledge Hub** and the Italian Network for Ecological Restoration, **RIRE**.

The BiodivRestore Knowledge Hub brings together around 50 experts from ecology, social sciences, land management and law. Its work is evidence-based, implementation-oriented and stakeholder-driven, reflecting the fact that **restoration is not only an ecological matter** as its successful implementation also depends on governance, planning, financing, interdisciplinary capacity and participation.

biodiversa+ European Biodiversity Partnership

RIRE RETE ITALIANA RIPRISTINO ECOLOGICO

Bringing damaged ecosystems back to life

RIRE, the Italian Network for Ecological Restoration, connects people and organisations working to restore degraded ecosystems in Italy — from forests and farmland to rivers, coasts and marine areas. It helps share knowledge, good practices and scientific expertise, while supporting the implementation of European and national nature-restoration policies. As a national example of cooperation among research, public institutions, businesses and civil society, RIRE helps bridge science, policy and practice through advice, training, working groups and consultation

A 2025 BiodivRestore dialogue with representatives responsible for Nature Restoration Regulation implementation in 20 Member States identified several recurring challenges.

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AI 4 Soil Health

DIALOGUE 1 Soil Health and Nature Restoration: Governance, Methods & Data

Monitoring, assessment and decision-support tools

Quantitative soil-health assessment with SHERPA

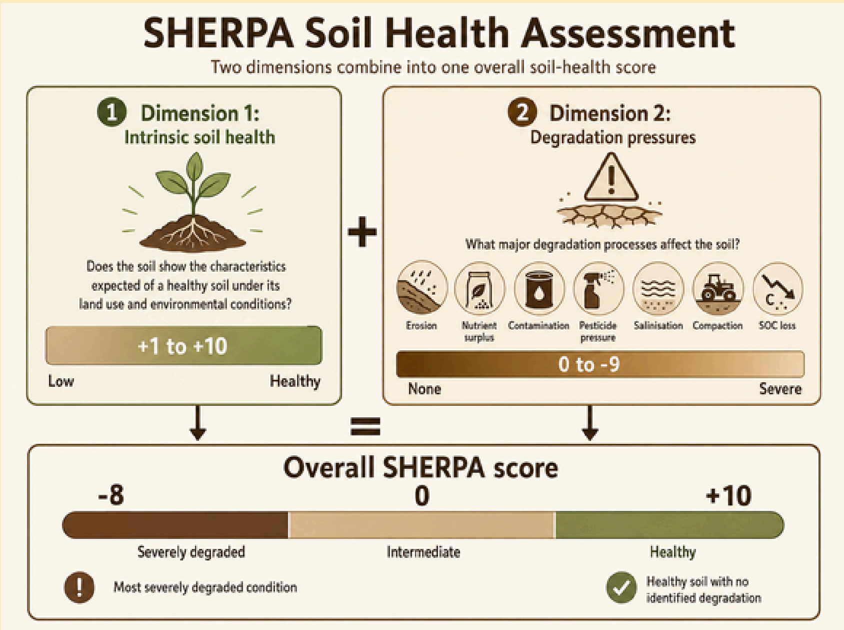
Christine Alewell | University of Basel

University of Basel
Environmental GeoSciences

"We do not only need to know whether soils are degraded; we need to quantify which processes are driving that degradation."

Christine Alewell presented **SHERPA** — Soil Health Evaluation, Rating Protocol and Assessment — as an **open and evolving framework for the quantitative assessment of soil health** across different European land uses.

SHERPA combines two dimensions. Dimension 1 evaluates intrinsic soil health: whether a soil displays the characteristics expected of a healthy soil under its specific land use and environmental conditions. Dimension 2 evaluates major degradation processes, including erosion, nutrient surplus, contamination, pesticide pressure, salinisation, compaction and soil organic carbon loss. Intrinsic soil health is scored positively from 1 to 10, while degradation pressures receive scores from 0 to −9. Their combination produces an **overall soil-health score** ranging from 10 for a healthy soil with no identified degradation to −8 for the most severely degraded condition.



SHERPA (Soil Health Evaluation, Rating Protocol, and Assessment) is a framework designed to turn the complex idea of "soil health" into a clear, quantitative score. It combines a soil's intrinsic health, based on its natural characteristics and land use, with the negative effects of degradation pressures such as erosion, nutrient surplus, pesticides, contamination and compaction. This makes it possible to compare soil health across regions and land uses, track changes over time and support more targeted management and policy decisions.

The indicators used for intrinsic soil health **differ by land use**. Forest assessment considers factors such as climate, geology, altitude and humus-layer characteristics. Permanent grasslands are assessed partly through vegetation cover, while croplands, orchards and vineyards are evaluated using year-round soil cover, soil structure and the proportion of organic fertiliser. A wetland component is under development, with drainage and vegetation condition considered as possible starting points.

The published European assessment applied SHERPA to 3,534 cropland sites, 637 grassland sites and 186 forest sites with sufficiently complete data. The results confirmed widespread degradation in agricultural soils. Approximately 99% of assessed cropland sites scored below 5 and around 85% below 2.5. The principal pressures were soil erosion, nitrogen and phosphorus surplus, soil organic carbon loss and pesticide risk. Southern European croplands generally recorded the lowest scores, while northern European sites performed comparatively better.

Grassland soils were only slightly healthier than croplands. Nitrogen and phosphorus surplus were the dominant pressures, with erosion also contributing in some regions. The results **challenge the assumption that permanent vegetation cover alone guarantees healthy soil** and point to the effects of nutrient loading on soil condition and biodiversity.

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Christine Alewell | University of Basel

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"We do not only need to know whether soils are degraded; we need to quantify which processes are driving that degradation."

Forest soils generally performed better, but the published analysis still identified substantial degradation, primarily associated with nitrogen surplus and heavy-metal contamination. The presentation also included a larger, preliminary forest analysis based on 2,547 samples. In this dataset, almost half of the sites scored below 5. Preliminary modelling suggested that worsening soil-degradation scores were associated with increasing forest defoliation, alongside important climatic influences. The same preliminary analysis found no clear influence of intrinsic soil health (Part 1) on defoliation; the association was specific to the degradation-pressure scores (Part 2). *Plese note these results are preliminary and should not yet be treated as final findings.*

Further preliminary applications illustrated how SHERPA might support more targeted management. In **Mediterranean olive orchards**, the assessed soils were generally **more degraded than the European cropland average**, particularly where extensive bare soil increased erosion and carbon loss. Examples from the Ionian Islands showed that relatively simple nature-based practices, including maintaining vegetation cover and managed grazing, could improve soil protection. Alewell stressed that s**uccessful uptake also depends on communication with farmers**, including addressing the belief that ground vegetation necessarily competes with olive trees for water and nutrients.

SOiL O-LiVE

What happens beneath an olive tree can make a big difference above ground. <u>SOIL O-LIVE</u> is studying the health, biodiversity and functioning of soils across Mediterranean olive-growing areas, looking at how different farming practices affect both the soil and olive production. The project has analysed thousands of soil samples to help identify practices that can keep olive groves productive while protecting the living soil they depend on.

Andalusia, Spain | Photo: P. Borrelli

For wetlands and peatlands, the SHERPA assessment key is not yet complete. Initial remote-sensing work found consistent differences between natural and drained peatlands using indicators such as NDVI, the GI Index, EVI and albedo. Freely available Sentinel-2 imagery performed nearly as well as higher-resolution PlanetScope data. This work may support the future development of SHERPA scores for wetlands, but it remains under review and is not yet an operational European mapping system.

A major strength of SHERPA is that it does not produce only a single final score. It **also identifies the individual pressures contributing to poor soil condition**, which can help guide management priorities and policy interventions. However, Alewell emphasised that the framework is still being tested, validated and revised.

The **main constraint is data availability**. Information on soil structure, compaction, site-specific fertiliser and pesticide inputs, pesticide spread and forest humus-layer disturbance remains incomplete. SHERPA currently supports point-based assessments rather than comprehensive European soil-health maps. Missing data are likely to overestimate soil health and underestimate the severity of degradation.

Alewell concluded that SHERPA should be understood as a **framework for testing, discussion and progressive improvement rather than a final regulatory tool**. With stronger monitoring data and further expert validation, it could support quantitative assessment under the Soil Monitoring Law. By identifying soil conditions and degradation pressures that influence ecosystem recovery, it could also provide evidence relevant to the implementation of the Nature Restoration Regulation.
Each parameter has to be tested, validated and improved by experts as SHERPA is continuously being updated.

Direct soil-biodiversity indicators are also not yet included. Although molecular techniques can characterise microbial communities, there is still no sufficiently harmonised interpretation of what these measurements mean for soil health across different land uses and environmental conditions. Soil structure and humus characteristics currently provide indirect evidence of biological functioning, but they do not replace direct biodiversity assessment.

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AI 4 Soil Health

DIALOGUE 1 Soil Health and Nature Restoration: Governance, Methods & Data

Monitoring, assessment and decision-support tools

Peatland forest management and soil-carbon modelling

Vince Chukwu | University of Aberdeen

"There is no single management option that will be optimal under all conditions. Decisions must balance climate mitigation, carbon retention, forest productivity and other ecosystem functions."

Vince Chukwu presented preliminary results from the HoliSoils project, examining how different **forest-management practices influence carbon dioxide emissions and soil organic carbon stocks** in forestry-drained peatlands in Northern Europe.

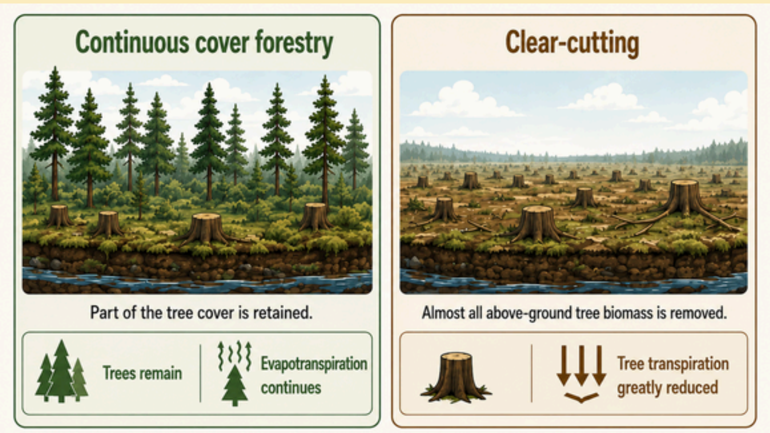
Looking beneath Europe's forests

Forest soils quietly store carbon, recycle nutrients and support the trees and biodiversity above them. **HoliSoils** brought together research, field experiments, monitoring and modelling to understand how forest management affects these vital soils and how healthier forest soils can contribute to climate action and resilient ecosystems. The project also developed maps, data and practical tools to support better forest management across Europe.

HoliSoils
Working together for forest soils

The study responds to a central policy and management challenge. Northern peatlands are major carbon stores, but drainage for forestry alters their hydrological conditions and can expose peat to decomposition, turning these ecosystems into significant sources of greenhouse-gas emissions. At the same time, forestry-drained peatlands remain productive landscapes that provide timber, biomass and income. Management decisions must therefore **reconcile climate mitigation with forest production and other ecosystem functions**.

The research compared two harvesting approaches:



These practices affect the peatland system through several interconnected mechanisms. The remaining trees under continuous cover forestry continue to regulate the water table through evapotranspiration, while clear-cutting generally raises the water table because tree transpiration is greatly reduced. Changes in vegetation, litter inputs and water-table levels can then influence peat decomposition, soil respiration and the balance of CO_2, CH_4 and N_2O emissions.

The presentation emphasised that these effects evolve over time. A harvesting practice may produce one response immediately after intervention and a different response as the forest regenerates. This makes **short-term measurements insufficient for judging long-term climate outcomes**.

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Monitoring, assessment and decision-support tools

Peatland forest management and soil-carbon modelling

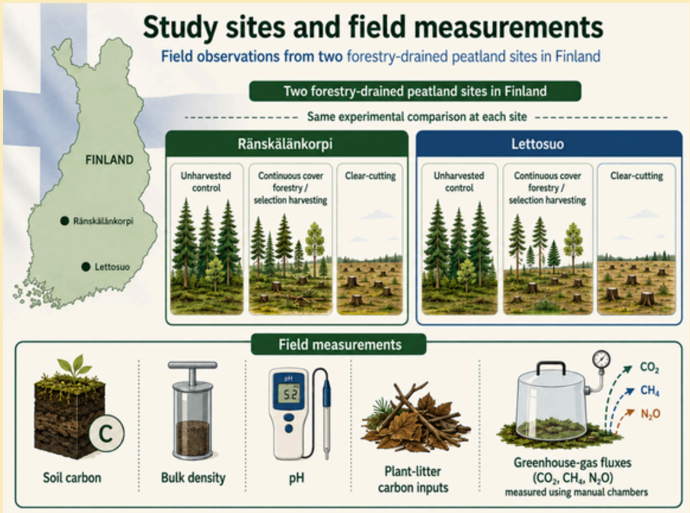
Vince Chukwu | University of Aberdeen

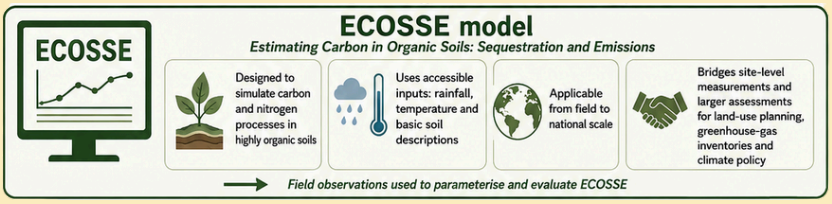
University of Aberdeen · Environmental Modelling Group · Luke Luonnonvarakeskus

“There is no single management option that will be optimal under all conditions. Decisions must balance climate mitigation, carbon retention, forest productivity and other ecosystem functions.”

The analysis used field observations from two forestry-drained peatland sites in Finland: **Ränskälänkorpi** and **Lettosuo**.

These observations were used to parameterise and evaluate the **ECOSSE model** – Estimating Carbon in Organic Soils: Sequestration and Emissions.





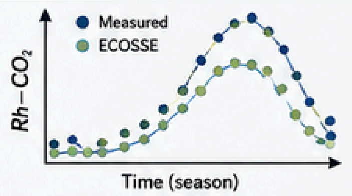
The first stage of the analysis tested how well ECOSSE reproduced measured heterotrophic respiration, expressed as Rh–CO_2. Overall, the model captured the main seasonal behaviour recorded at the two sites: higher respiration during warmer periods; - lower respiration during colder periods; and - the general timing and direction of changes under the different treatments.

The model performed particularly well outside the highest-emission peaks. During some peak periods the model diverged from measured values, and the direction of that bias varied by site.

After validation, the model was used to project heterotrophic CO_2 emissions and changes in soil organic carbon over a 50-year period, from 2020 to 2070.

Model performance

First-stage test of measured heterotrophic respiration Rh–CO_2



- Captured the main seasonal behaviour at both sites
- Higher respiration in warmer periods
- Lower respiration in colder periods
- Captured the general timing and direction of treatment differences
- Best performance outside highest-emission peaks
- Bias varied by site: overestimation at Ränskälänkorpi; underestimation at Lettosuo (Control and selection-harvesting plots)
- Overall agreement generally strong; bias not significant in most cases

Supports the use of ECOSSE to simulate carbon dynamics in forestry-drained peatlands, while performance varies by site and treatment

Long-term projections (2020–2070)

Ränskälänkorpi *Projected response*

Continuous cover forestry showed greater long-term potential to:
- reduce heterotrophic CO_2 emissions
- retain soil organic carbon

Site outcomes depend on ecological and hydrological conditions

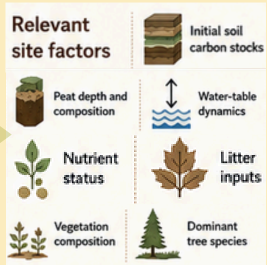
Lettosuo

Projected response

Clear-cutting showed greater soil organic carbon gains than continuous cover forestry

Site outcomes depend on ecological and hydrological conditions

The two sites responded differently. Forest-management outcomes cannot be generalised across all drained peatland forests.



Management and policy implications

- Decisions should be site-specific
- Avoid prescribing a single method without considering local ecological and hydrological conditions
- Combine field measurements, process-based modelling, long-term projections and local ecological knowledge
- Long-term consequences may not be visible from short observation periods alone
- Modelling should support — not replace — site-specific assessment and stakeholder decision-making
- Measures should be flexible and supported by long-term monitoring and modelling

Different objectives

- **Forest owners:** timber and biomass production
- **Governments:** greenhouse-gas mitigation
- **Researchers:** soil carbon and ecosystem processes
- **Conservation actors:** biodiversity and hydrological restoration

No harvesting method is universally superior. Climate and soil-carbon effects are context-dependent.

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- European Commission. The Nature Restoration Regulation. Official policy overview and implementation material.
- Nature Restoration Regulation Reference Portal. Frequently Asked Questions. Non-binding implementation guidance; it should not be presented as amending the legal text

Editorial note

*This Webinar Insight Brief has been prepared in the framework of the **AI4SoilHealth** Cross-Policy Soil Dialogues, a series of science–policy exchanges conceived and organised by **ISINNOVA** to foster dialogue across policy areas and explore how soil knowledge can better support policy implementation. This brief provides a concise summary of the webinar presentations and discussions, reflecting the main points raised by the speakers rather than providing verbatim records of their contributions.*

The key takeaways, cross-cutting insights and policy recommendations or implications presented in this brief are an interpretative synthesis developed by ISINNOVA, drawing on the webinar contributions and analysed within the project's science-for-policy framework. Unless explicitly attributed, these elements should not be understood as statements, recommendations or endorsements made by individual speakers or their organisations.

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