

Monitoring soil health in Scotland by land use category – a scoping study

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Summary

Monitoring of soil health in a changing climate is a priority for the Scottish Government.

In 2020, CXC published a baseline report that pulled together existing research on the vulnerability of Scottish soils to climate change¹. The report found that, while Scotland has a significant knowledge base on soils, there was no single indicator that could be applied to all soils, climatic conditions or land uses².

This scoping study takes the thirteen potential indicators that were previously identified and considers their strategic relevance to monitoring soil health in the context of existing land use Scotland. Ten pre-defined land use categories were considered. We have also considered how soil monitoring might be managed to inform our understanding of cross-cutting issues such as biodiversity and climate change. The categories are defined in the appendix.

Our approach

Each indicator was assessed for suitability for each of twelve categories using expert knowledge of soil properties and functions for Scottish soils, and interpretation of available data and relevant literature. Indicator suitability was ranked from *not suitable* to those being considered as a *primary soil health indicator* for the category under consideration.

Key points

- Potential primary soil health indicators were identified for several land use categories (Table 1)
- However, it is not possible to identify a single, definitive indicator for each individual land use category and suitable indicators were not identified for several categories such as *Urban* or *Amenity soils* (Tables 1, 2)

¹ <https://www.gov.scot/publications/climate-ready-scotland-second-scottish-climate-change-adaptation-programme-2019-2024/>

² <https://www.climateexchange.org.uk/research/projects/measuring-the-vulnerability-of-scottish-soils-to-a-changing-climate/>

- Seven indicators were considered extremely important for more than 50% of the categories assessed:
 - *soil organic matter content*
 - *topsoil depth*
 - *erosion features*
 - *bulk density*
 - *bacteria and archaeal diversity (DNA methods)*
 - *fungus and nematode diversity (DNA methods)*
- *Visual assessment of soils, moisture content and dissolved organic matter* were considered extremely important for the fewest categories, though *moisture content* was considered the primary indicator for transport infrastructure

The issue of dependency between indicators generates a layer of complexity that requires further exploration.

Conclusions

This scoping study has clarified which indicators may be directly relevant to monitoring soil health within different land use categories across Scotland. Further work will be required to explore how they might be applied in specific land use management and policy contexts, and to understand the impacts, if any, of interactions between the indicators under changing conditions.

Table 1: Summary table highlighting indicators considered either *extremely important* or *not suitable* for the listed categories. Categories highlighted in **bold** are considered a primary soil health indicator for the category.

Indicator	Land Use Category* suited to	Land Use Category* unsuited to
Dissolved organic carbon – high levels indicate loss of carbon from organic soils, which can be symptomatic of soil degradation	Environmentally sensitive areas; Peatlands; Transport infrastructure; Climate change	n/a
Moisture content – low levels imply carbon loss in organic soils; high moisture levels reduce soil strength and increased risk of failing (e.g., landslip)	Arable; Peatlands; Transport infrastructure	Open upland habitats; Urban
Soil organic matter content – linked to storage and supply of water and nutrients; also directly linked to carbon storage in soils	Agriculture (uncultivated); Open upland habitats; Environmentally sensitive areas; Grassland; Arable; Peatlands; Transport infrastructure; Biodiversity; Climate change	n/a
Nutrient flux – supports plant growth when balanced with requirements; excess flux linked to runoff and water pollution	Environmentally sensitive areas; Arable; Peatlands; Biodiversity; Climate change	Urban; Transport infrastructure
Topsoil depth (or total depth for peat) – indicative of suitability for cropping & grassland and can be used to monitor soil erosion; for peat, indicative of carbon storage and for monitoring loss of peat through erosion or oxidation; thicker topsoil implies more habitat for soil biodiversity if not compacted	Agriculture (uncultivated) ; Open upland habitats; Environmentally sensitive areas; Grassland; Arable; Peatlands; Biodiversity; Climate change	Urban; Amenity
Visual evaluation of soil structure - in topsoils and subsoils of cultivated land rather than for semi-natural soils, strongly linked to plant rooting, water infiltration & buffering and erosion risk due to surface runoff	Grassland; Arable	Peatlands; Forestry; Urban

Indicator	Land Use Category* suited to	Land Use Category* unsuited to
Erosion features – indicative of poor soil structure and limited infiltration; bare soil has greater risk of further soil loss irrespective of soil structural condition	Agriculture (uncultivated); Open upland habitats; Environmentally sensitive areas; Peatlands; Forestry; Biodiversity; Climate change	n/a
Bulk density – linked to the ability of plants to develop roots and access nutrients; indicates presence or risk of compaction and potential for reduced water infiltration or increased runoff	Agriculture (uncultivated); Open upland habitats; Environmentally sensitive areas; Grassland; Arable; Peatlands; Forestry; Biodiversity; Climate change	n/a
Bacteria and archaeal diversity (DNA methods) – indicative of rhizospheric (root zone) and bulk soil diversity, insight into soil functionality and a perceived measure of resilience to disturbance	Agriculture (uncultivated); Open upland habitats; Environmentally sensitive areas; Grassland; Arable; Peatlands; Forestry; Urban; Biodiversity; Climate Change	Transport Infrastructure
Fungal diversity (DNA methods) - indicative of rhizospheric (root zone) and bulk soil diversity, insight into soil functionality and a perceived measure of resilience to disturbance	Agriculture (uncultivated); Open upland habitats; Environmentally sensitive areas; Grassland; Arable; Forestry; Urban; Biodiversity; Climate Change	Transport Infrastructure
Nematode diversity (DNA methods) - indicative of rhizospheric (root zone) and bulk soil diversity, a recognised proxy measure of soil functionality, highlights plant pathogenic species	Agriculture (uncultivated); Open upland habitats; Environmentally sensitive areas; Grassland; Arable; Forestry; Urban; Biodiversity; Climate Change	Transport Infrastructure
Earthworm diversity (morphology) - a proxy measure of soil function	Environmentally sensitive areas; Grassland; Arable; Forestry; Urban; Biodiversity	Peatlands; Amenity; Transport Infrastructure
Functional genes – indicative of soil nutrient cycling and process rates and cycling	Environmentally sensitive areas; Grassland; Arable; Peatlands; Climate change	Amenity; Transport Infrastructure; Biodiversity

* for category definitions, see appendix

Table 2: Assessment of the importance of the thirteen potential indicators (as previously identified) to the vulnerability of Scottish soils to climate change by category. Importance has been assessed based on expert judgement and experience of how these indicators reflect the ability of the soil to either provide a function or to protect against the loss of the function. Indicators represent those in which we have the greatest confidence in their robustness and integrity².

N: Little or no importance; ++: Moderately important; +++: Extremely important; +++++: Considered a primary soil health indicator for this category.

	Semi-natural land			Agriculture (cultivated)		Peatlands	Forestry	Urban	Amenity (Leisure)	Transport infrastructure	Biodiversity (cross-cutting)	Climate change (cross-cutting)
	Agriculture (uncultiv.)	Open upland habitats	Environ. sensitive areas (e.g., Machair)	Grassland	Arable							
<i>Dissolved organic carbon</i>	++	++	+++	++	++	+++	++	++	++	+++	++	+++
<i>Moisture content</i>	++	N	++	++	+++	+++	+++	N	++	++++	++	++
<i>Soil organic matter content</i>	+++	+++	+++	+++	+++	+++	++	++	++	+++	+++	++++
<i>Nutrient flux</i>	++	++	+++	++	+++	+++	+++	N	++	N	+++	+++
<i>Topsoil depth (or total depth for peat)</i>	++++	+++	+++	++++	++++	++++	++	N	N	++	+++	++++
<i>Visual evaluation of soil structure (topsoil/subsoil)</i>	++	++	++	+++	+++	N	N	N	++	++	++	++
<i>Erosion features</i>	+++	++++	++++	++	++	+++	+++	++	++	++	++++	++++
<i>Bulk density</i>	+++	+++	+++	++++	++++	+++	+++	++	++	++	+++	++++
<i>Bacteria and archaeal</i>	+++	+++	++++	++++	++++	++++	+++	+++	++	N	++++	+++

	Semi-natural land			Agriculture (cultivated)		Peatlands	Forestry	Urban	Amenity (Leisure)	Transport infrastructure	Biodiversity (cross-cutting)	Climate change (cross-cutting)
	Agriculture (uncultiv.)	Open upland habitats	Environ. sensitive areas (e.g., Machair)	Grassland	Arable							
<i>diversity (DNA methods)</i>												
<i>Fungal diversity (DNA methods)</i>	+++	+++	++++	++++	++++	++	++++	+++	++	N	++++	+++
<i>Nematode diversity (DNA methods)</i>	+++	+++	++++	++++	++++	++	+++	+++	++	N	++++	+++
<i>Earthworm diversity (morphology)</i>	++	++	+++	++++	++++	N	+++	+++	N	N	++++	++
<i>Functional genes</i>	++	++	+++	++++	++++	+++	++	++	N	N	N	++++

Appendix

Land use categories subject to analysis in this report are defined in the following table. Further work will be required to explore each category, soil types and management practices in more detail.

Text in *italics* represents groupings reported in Scotland's Third Land Use Strategy 2021-2026³:

Category		Comment
<i>Semi-natural land</i> (Hill land, mountains and moors)	Agriculture (uncultivated)	hill land, mountains and moors used for extensive grazing
	Open upland habitats-	other hill land, mountains and moors not used for extensive grazing
	Environmentally sensitive areas	including <i>coastal</i> Machair and fragile tundra soils of the high mountain tops; and agricultural areas that require special protection because of landscape, wildlife, or historical value
<i>Enclosed farmland</i>	Agriculture (cultivated)	improved grassland for intensive grazing
	Agriculture (cultivated)	arable land
Peatlands with semi-natural vegetation and some forestry	Subset of <i>semi-natural land</i>	provides some of Scotland's iconic landscapes
Forestry - and native woodland habitats		found in a wide range of landscapes including urban forests, commercial forestry, amenity woodlands
<i>Settlements</i> – urban and suburban	Urban soils	such as domestic garden, roadside verges
	Amenity soils	such as parklands, golf courses
Transport infrastructure		road and rail networks especially those vulnerable to landslip
Biodiversity		(cross-cutting)
Climate change		(cross-cutting)

³ <https://www.gov.scot/publications/scotlands-third-land-use-strategy-2021-2026-getting-best-land/>

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