climate change

Scotland's centre of expertise connecting climate change research and policy

CXC Briefing note: Scoping a national peatland monitoring framework

1.1 Background

Significant funding is being invested in restoring degraded peatlands to a stable condition. As work progresses, it is important to understand what techniques are working, where problems exist, and how the overall condition of Scotland's peatlands are understood.

The National Peatland Plan identifies the need for a framework to measure – and demonstrate – benefit from Scotland's peatlands. The Research and Monitoring Group were identified as the lead group, and a series of issues were identified for consideration, including methods, scale, timescales and scientific specialisms.

1.2 CXC involvement

In August 2017 CXC were asked to support discussions around peatland monitoring. We hosted a workshop of key stakeholders in 2018 to explore two key questions:

1. What do we want to be able to say about the relative condition of the peatland resource?
2. How can we start to build a monitoring framework?

1.3 The Working Paper

To build on the workshop, we asked expert researchers at the James Hutton Institute to explore the current state of confident knowledge on different aspects of monitoring.

The paper is laid out as a series of issues that cover:

- Underlying principles – why is peatland monitoring important?
- Language – where is there common language for key terms such as condition and peatland health?
- What can we monitor now (understanding current indicators) and what further work is needed?
- The legislative and policy targets for climate change and biodiversity. These are not mapped directly to the national outcomes, but may provide a starting point for discussion.

The paper includes details of complex scientific monitoring processes. It was originally drafted as a consultation paper, with questions at the end of each section that can guide the thinking of policy colleagues and practitioners in the process of building a framework.

1.4 What next?

The paper was designed to form a basis for discussion. It might be helpful to think in terms of the National Performance Framework, which discusses monitoring progress in terms of 'how well Scotland is doing'.

What are the key outcomes that peatland restoration delivers to, and therefore what indicators might inform our understanding of performance?

1.5 Questions for policy colleagues

The paper is lengthy and covers some complex scientific techniques. We do not expect policy colleagues to engage with this level of detail.

A useful first step might be to consider the following questions.

1. What does success look like for Scotland's peatlands?
2. Should the framework consider the whole of the peatland resource?
   a. Is it useful to understand overall condition – both good and degraded?
3. What does successful restoration look like?
   a. What are the key timeframes and how might annual reporting be framed, given that full restoration can take 15 – 20 years)?
4. How does peatland restoration fit within the wider monitoring of ecosystem function and natural capital in Scotland?
5. How might the peatland resource fit within the wider monitoring of soil health in Scotland?

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A working paper: Scoping a national peatland monitoring framework

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1. Executive summary

Scotland is a peat-rich nation. Healthy peatlands deliver a wide range of ecosystem services, including carbon sequestration, carbon storage and a specialised biodiversity. Degraded peatlands are a large source of carbon dioxide and other greenhouse gas emissions and have a much-reduced biodiversity value. This gives peatlands a critical role in reducing greenhouse gas emissions.

Much of Scotland's peat resource is damaged: eroding, drained or converted to other land uses. The Scottish Government has made a significant commitment to restore peatland areas that have been damaged.

1.1 Monitoring peatlands

This paper explores how we can monitor success. Peatlands restored to a functioning ecosystem can better withstand a changing climate and also provide vital flood risk protection. It takes time for the benefits of restoration to take effect. Long-term monitoring is important to track this recovery and prompt intervention when necessary. Despite significant investment in peatland restoration we still have a lot to learn, particularly on the best techniques to use, and in understanding how long the process takes.

We start with the qualities that are important for peatlands in terms of climate change and biodiversity, including water storage, carbon storage and habitat condition, and examine the potential of taking an ecosystems-based approach to monitoring. Complete monitoring of peatland health will also need to include issues such as water quality and natural flood management.

The relevant policy targets are set against the current and potential delivery mechanisms in the context of the current state of monitoring and reporting. Working through a series of questions the report captures what is already in place, what is still in development and how we can begin to prioritise next steps and specific actions:

1. What are the policy targets that a monitoring framework needs to deliver to?
2. How are key terms such as peatland 'health', 'condition' and 'restored' defined in relation to policy targets?
3. Which potential condition indicators could be included in the monitoring framework?

4. What protocols and technologies already exist for condition indicator monitoring that can be deployed or adapted?
5. Which indicators may require further method development?
6. How critical is it to agree appropriate monitoring timeframes for each indicator?
7. How can appropriate spatial sampling density and extent be estimated for each indicator?
8. What are the strengths, weaknesses, opportunities and threats of potential identified indicators and what gaps remain?

The development of a monitoring framework is a big task involving stakeholders from several societal sectors, and this report can be seen as a first step. Multiple stakeholders have an interest in getting this right, and it is important that everyone has a chance to contribute to the best way forward. This includes people who live and work in peatland areas, as well as those who are expert in the science and the policy specialists who help with the process of making decisions.

1.2 Next steps

The essence of a peatland monitoring framework is to monitor condition, changes in condition, and evaluate whether current management or restoration activities are working effectively or not. Although there is statutory monitoring on areas protected for nature conservation and some ad hoc monitoring for research purposes, there is currently no national peatland monitoring framework for Scotland that encompasses a representative sample of the peatland resource.

This report aims to provide a starting point for the decisions needed to develop and run a peatland monitoring programme. It is hoped that it will inform the necessary action as we look to achieve a healthy and thriving peatland resource in Scotland over the next 20 years.

2. Contents

3. Introduction

This paper examines the underpinning information to enable informed discussion among key stakeholders about the state of monitoring in Scotland's peatlands in relation to biodiversity and climate change commitments[1].

It sets out the relevant policy targets against the current and potential delivery mechanisms and examines the state of monitoring and reporting. Working through a series of questions (1-8, below) it captures what is already in place, what is still in development and how we can begin to prioritise next steps and specific actions.

1. What are the policy targets that a monitoring framework needs to deliver to?
2. How are key terms such as peatland 'health', 'condition' and 'restored' defined in relation to policy targets?
3. Which potential condition indicators could be included in the monitoring framework?
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8. What are the strengths, weaknesses, opportunities and threats of potential identified indicators and what gaps remain?

While the main report was submitted in 2020, a later decision to make this report an openly available document necessitated a few changes to reflect updates in critical figures or knowledge. Such changes to reflect more up to date information up to January 2023 are indicated by insertions in brackets and prefaced UPDATE throughout the test. Due to time constraints to provide this further revision, only the most critical issues have been checked for updates and thus the addenda may not provide all relevant updates that may be required.

[1] Natural flood management, water quality and cultural aspects of peatland functions, and policy targets relating to these functions, were considered out of scope for this paper.

3.1 Scotland's peatland resource

Peat is defined as a purely organic soil that originates entirely from partly decomposed plant material and has accumulated due to historic and/or current water logging. Scotland is a peat-rich nation; almost a quarter of the land area harbours peat soils below the surface vegetation. Peat shapes the way we use our land and contributes to our landscapes, culture and heritage.

Peatlands are defined as any areas of land with a naturally formed layer of peat soil and so occupy the same land area. This definition means that it is not only near-natural habitats on peat soil, such as blanket bog, lowland raised bog, or fen, marsh or swamp, but also any degraded types of such former habitat which can include farmed, extracted, built-up, afforested land as well as areas converted to grassland vegetation, that are still called 'peatlands' (IUCN, 2014[2]; Clarke and Joosten, 2002[3]; Ramsar Convention, 2002[4]). Many of our most iconic views are framed by peatland habitats. Scotland's peatlands have significant value as ecosystems supporting Scotland's biodiversity. In recent years the value of peatlands as a carbon store has been given more prominence. In addition, peatlands in good condition are net carbon sequestering ecosystems (i.e. they lock up carbon) and thereby help mitigate the long-term effects of climate change.

Mapping peatlands has always been challenging because peat can form in small pockets amongst other soil types, where local conditions have allowed for peat formation in either parts or all of the period since the last ice age. Alternatively, in regions of high rainfall and a low level of evapotranspiration, they can cover very large and uninterrupted areas as if they were blankets and indeed the name 'blanket bog' is derived from this visual feature. The challenge to map peat soils is ongoing[5] and, although the estimates for the total area concerned have not changed much in the last 10 years, it is not always clear where exactly in a landscape the peat is located. Estimating the condition of peatland from GIS intersections of habitat and land cover survey data on peat soils maps is therefore creating some remaining uncertainty as to the current condition of our peatlands at national scale. However, our most up to date evidence suggests that as much as 75-80% of Scotland's former blanket bogs[6,7], over 90% of the former lowland raised bogs[8] and most of our former

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[2] http://www.iucn-uk-peatlandprogramme.org/sites/www.iucn-uk-peatlandprogramme.org/files/1%20Definitions%20final%20-%205th%20November%202014.pdf

[3] http://www.imcg.net/media/download_gallery/books/wump_wise_use_of_mires_and_peatlands_book.pdf

[4] http://archive.ramsar.org/pdf/res/key_res_viii_11_e.pdf

[5] https://onlinelibrary.wiley.com/doi/full/10.1111/sum.12491

[6] https://uk-air.defra.gov.uk/assets/documents/reports/cat07/1904111135_UK_peatland_GHG_emissions.pdf

[7] https://soils.environment.gov.scot/maps/thematic-maps/carbon-and-peatland-2016-map/

[8] https://scottishwildlifetrust.org.uk/docs/002_057__restorationoflowlandraisedbogsinscotland_jan2013_1359568030.pdf

fens, marshes, swamps and reed beds[9] are no longer in peat-forming condition and are currently emitting greenhouse gases[6].

The net emissions from Scotland's peatlands have recently been estimated as potentially as high as 9.7 Mt carbon dioxide (CO_2) equivalents per year, due to the high proportion of peatland in poor condition[10] (UPDATE: The 1990-2020 UK Inventory is the most recent submission at present and suggests 6.42 Mt CO_2 equivalents emissions for Scotland[11]) . This is close to the total current carbon fixation achieved by Scotland's woodland (sequestration of 9.5 Mt CO_2 equivalent; 2017 figures[12]; UPDATE the estimated net sink for Forestry in 2020 for Scotland was -6951 kt CO2e). These emissions could potentially be mitigated, through restoration efforts, to achieve at least net zero emissions from peatlands if near natural condition can eventually be achieved[6]. In the period to 2045-50, however, peatlands would still continue to be a, albeit smaller, source of emissions.

3.2 The current position

There is a wealth of existing data, both as historic datasets and on-going site-specific monitoring. This provides a strong basis on which to build. Before deciding on the collection of new metrics, wider consultation with key stakeholders is recommended to identify and confirm:

a. The specific purpose(s) for which metrics for indicators are collected (including monitoring of delivery to target outcomes)
b. Key parameters that should be standardised across collection protocols
c. Cross-sectoral interest in multi-functional datasets and indicators.

This report provides a summary of the state of knowledge around such potential indicators and a series of questions that could facilitate stakeholder discussions, prioritisation attempts for key indicators and design of the spatial and temporal facets of a future monitoring network. There are similar ongoing efforts to facilitate a "core list of outcome measures that could be used to study and monitor restoration outcomes" at UK level funded by the Natural Environment Research Council (NERC; via the Valuing Nature Programme) and ESRC, and in collaboration with IUCN, Defra and the United Nations. Internationally, the Food and Agriculture Organization of the United Nations (FAO) has also begun similar evidence gathering to inform future global peatland monitoring via the Global Peatlands Initiative[13]. These initiatives, however, have a slightly different focus, with the former being oriented on providing indicators of tipping points in UK blanket bog peatlands,

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[9] An estimate for this cannot be given as there has been no systematic survey to identify the locations of the peat underlying former fens, marshes, swamps and reed beds. Our data on condition of these minerotrophic habitats stem from the remaining areas under nature protection.
[10] https://www.theccc.org.uk/wp-content/uploads/2018/11/Quantifying-the-impact-of-future-land-use-scenarios-to-2050-and-beyond-Full-Report.pdf
[11] https://uk-air.defra.gov.uk/assets/documents/reports/cat09/2206220830_ukghgi-90-20_Main_Issue1.pdf
[12] https://www.gov.scot/publications/scottish-greenhouse-gas-emissions-2017/
[13] http://www.fao.org/3/CA8200EN/CA8200EN.pdf ; https://www.globalpeatlands.org/

which could also be partly used to monitor restoration, but not directly targeting metrics for international reporting obligations. The FAO report, understandably, focuses on the large data gaps in our understanding of where peatlands occur globally, and what condition these are in. It highlights some of the existing condition reporting also referred to here, and touches on future monitoring potential through utilisation of Earth Observations validated through field-based data.

Peatlands serve a variety of functions, and this paper will address peatland biodiversity and climate change. Other important issues including natural flood management, water quality and cultural services will also require attention, but are not considered in this paper.

4. What are the policy targets that a Scottish Peatland Monitoring Framework needs to deliver to?

4.1 Scottish policy commitments for peatlands

In 2015, Scotland's National Peatland Plan was published[14]. It sets out a vision for the peatland resource in 2020, 2030, 2050 and beyond (Box 1) and established practical mechanisms that would help deliver that vision. This includes a National Peatland Group (NPG) which seeks to "promote, facilitate and monitor delivery of the National Peatland Plan". The NPG is supported by the National Peatland Research and Monitoring Group (NPRMG), which is responsible for ensuring "research and monitoring focuses on delivering effective restoration and management". (UPDATE: The NPRMG has now been reformed as the S/TAG). We discuss the specific legislation, policies and targets that aim to deliver the Peatland Plan's vision in relation to biodiversity and climate change.

Box 1. Vision of the National Peatland Plan

By 2020 we expect to see improvements in the protection and condition of peatlands. They will be valued by government policies, developers, land managers and the wider public and no longer seen just as special interest habitats. The public will embrace peat-free composts. Public funding remains the main source of support for peatland management and restoration, but the level of private funding is increasing. We will have in place a network of demonstration sites for good management, a Peatland Code supporting private funding of peatland conservation and restoration, and peatland management included in national carbon accounting. All of our statutory protected areas should be in, or moving towards, favourable condition – an exemplar of good management in rural Europe. The Flow Country will have moved from the UK Tentative List towards being a fully "inscribed" World Heritage Site.

By 2030 we want to see peatlands in a healthy state and widely regarded as resilient. By now there will be global recognition of the multiple benefits of peatlands to society, reflected in the level of support directed at ensuring their management as healthy ecosystems. Funding for stewardship will have extended from public to private sources, with appropriate rewards for the benefits derived from the peatlands' natural capital and the services flowing from their healthy ecosystem functions. By now, peatlands are viewed as essential to the nation's wellbeing and natural capital.

2050 and beyond the rewards of restoration effort undertaken in previous decades should now be evident. The effects of a changing climate will be more apparent, but our peatlands are coping where restoration and sound management have increased their resilience. Restoration work continues and management to secure and maintain multiple benefits is the norm, with the income from this helping to maintain rural skills and employment.

[14] https://www.nature.scot/climate-change/taking-action/carbon-management/restoring-scotlands-peatlands/scotlands-national-peatland-plan

4.1.1 Climate change

The original Climate Change (Scotland) Act 2009[15] set a target of an 80% reduction of Scottish net emissions relative to the 1990 baseline year. The Scottish Government published the Climate Change Plan[16] in 2018, setting out the policy outcomes by which Scotland's statutory emissions reduction targets from 2018 to 2032 will be met. A monitoring report was published in October 2018 to provide more detailed information on progress in implementing the plan[17]. In 2019, Scottish Government agreed to meet a target of net-zero emissions by 2045, as advised by the UK Committee on Climate Change (CCC)[18]. The Climate Change (Emissions Reduction Targets) (Scotland) Act received Royal Assent at the end of October 2019[19]. This Act amends the original Climate Change (Scotland) Act 2009 and contains more stringent interim targets for 2020, 2030 and 2040 (56, 75 and 95% lower than baseline, respectively) alongside the 2045 net zero target.

The current Climate Change Plan (2018) includes a commitment to continue and enhance the restoration of peatlands. The two main policy targets for peatland restoration efforts are to achieve 50,000 hectares restored by 2020, and 250,000 hectares by 2030 (Climate Change Plan, 2018, p.182; UPDATE: The current Update to the Climate Change Plan 2018 – 2032[20] reiterates these targest but adds a minimum annual restoration target of at least 20,000 ha). The National Peatland Plan (2015) sets out the targets mentioned above (Box 1) in relation to peatlands generally. In addition, there is also potential conflict with the woodland expansion targets, because, although there is a presumption against establishing new woodland on peat or where it would compromise adjacent peatland habitat, woodland replanting may still be considered under certain circumstances. Further policies that contain measures on peatlands concern prescribed burning (muirburn) and Scottish planning policy in relation to peat extraction and wind farm construction. Although these contain guidance on practices, which for the most part advise to avoid peatland areas, there appears to be no formal monitoring or reporting in relation to these policies. Further details can be found in Appendix 1.

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[15] https://www.legislation.gov.uk/asp/2009/12/pdfs/asp_20090012_en.pdf

[16] https://www.gov.scot/binaries/content/documents/govscot/publications/report/2018/02/scottish-governments-climate-change-plan-third-report-proposals-policies-2018/documents/00532096-pdf/00532096-pdf/govscot%3Adocument

[17] https://www.gov.scot/publications/climate-change-plan-monitoring-report-2018/pages/6/

[18] https://www.theccc.org.uk/wp-content/uploads/2019/05/Net-Zero-The-UKs-contribution-to-stopping-global-warming.pdf

[19] Climate Change (Emissions Reduction Targets) (Scotland) Bill. https://www.parliament.scot/parliamentarybusiness/Bills/108483.aspx

[20] https://www.gov.scot/binaries/content/documents/govscot/publications/strategy-plan/2020/12/securing-green-recovery-path-net-zero-update-climate-change-plan-20182032/documents/update-climate-change-plan-2018-2032-securing-green-recovery-path-net-zero/update-climate-change-plan-2018-2032-securing-green-recovery-path-net-zero/govscot%3Adocument/update-climate-change-plan-2018-2032-securing-green-recovery-path-net-zero.pdf

Following the passing of the Climate Change (Emissions Reduction Targets) (Scotland) Act 2019, the Climate Change Plan is due to be amended[21] to consider the increased challenge to achieve net zero by 2045 (UPDATE: Please see link to update above). The Committee on Climate Change[16] report contained an analysis of how different sectors could contribute further to enhanced ambitions to reduce emissions (termed "Further Ambition" options, which included mention of potentially raising the target for peatland restoration across the UK to 55% of the land area from the current 25% target. At the current estimate of peatland area in Scotland (1.9 mi hectares [6]), this would be 1.04 mi hectare. There is also a further, "Speculative Options", scenario, which would involve an even higher total area to be restored by 2050 (75%; 1.4 mi hectare). Globally, emissions must fall by at least 7.6% annually now in order to have a >40% chance to stay below 2 degrees of post-industrial warming[22].

The Scottish Government is investing significant amounts of funding into the restoration of damaged peatland in order to achieve the current targets in the Climate Change Plan. To the end of the 2018-19 financial year, over £20.3 million has been spent on peatland restoration, and in the current financial year, another £14 million is available for restoration with up to £12 million being delivered through Peatland ACTION (within Scottish Natural Heritage)[23]. Since the project started in 2012, Peatland ACTION has delivered restoration activities on over 19,000 hectares of peatland habitat (figure released as of end of March 2019)[19]. ADD: The figure as per end of 2021 is 36,000 ha. These figures can probably (assuming there is no spatial overlap) be added to the estimate given by Evans et al (2017) in their report to UK BEIS[6], which estimated that 21,326 ha of restoration activities had already been delivered via other sources of funding between 1991 and 2013. These data suggest that a total of 40,326 ha has been delivered to the end of March 2019, against a current target for 2020 of 50,000 ha. (UPDATE: Peatland restoration delivered via the Agri-Environment Climate Scheme (AECS) are not yet included in this figure and neither are other restoration via e.g. post-2013 renewables projects.

Clearly, these are already challenging targets to deliver, and higher targets as outlined in the CCC's scenarios would increase this pressure, however, restoration activities have stepped up in terms of the total areas restored per year. In 2018 - 2019 Peatland ACTION delivered restoration activities on an estimated 5,800 ha of peatland habitat; the largest amount in a given year so far and against a spend of £7.261 million[19]. With the increased funding in the current financial year, and the increased knowledge on how to deliver effective peatland restoration that has been built up within this body over the past 8.5 years, proportionally higher restoration area outcomes can be expected to close the gap to the current 2020 Climate Change Plan target and the existing 2030 target. However, at the current restoration rate, the existing 2030 and 2045 targets would be missed.

Whilst there are monitoring instruments in place for the wider complement of **restoration area** targets specified in the climate change legislation and associated policies above, the National Peatland Plan calls for a monitoring programme that can "audit **both habitat losses**

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[21] https://www.gov.scot/policies/climate-change/

[22] https://www.unenvironment.org/interactive/emissions-gap-report/2019/

[23] Peatland ACTION – COMMS – Briefing note – Scottish Government – 21 August 2019 (update to A2984602) (A3037845).pdf; available via contact with Peatland ACTION.

and restoration work and their **outcomes**". From a climate change perspective, the entire peatland area may be under threat, given that we are already living in a world that is 1 degree warmer than pre-industrial levels[24] and, if the current trajectory for greenhouse gas concentrations continues, temperatures may increase to 1.5 degrees C higher than pre-industrial levels by 2030-2052[25]. The current projections for the UK are for higher temperatures, but also for significant changes in rainfall patterns[26]. UK peatlands are ecosystems that have formed under a typically relatively cool and wet climate and so may be sensitive to climate change in both restored and good condition. We therefore need to monitor not only peatland restoration and its effectiveness in terms of emissions, but also the condition and emissions of the wider peatland environment with a view to targeting intervention to ensure no further degradation.

At UK national level, emissions within the Land Use, Land Use Change and Forestry (LULUCF) sector are reported annually in the UK Greenhouse Gas Inventory[27] under United Nations Framework Convention on Climate Change (UNFCCC) and Kyoto Protocol obligations. For peatlands, specific guidance on how to account for national emissions was given in the 2013 Wetland Supplement[28], published by the Intergovernmental Panel on Climate Change (IPCC), however, at the time of writing, the methodology has not yet been implemented in the UK Greenhouse Gas Inventory and, at present, reporting of peatland emissions are carried out using the 2006 IPCC Guidelines, which significantly underestimate real emissions. (UPDATE Peatland emissions as per the Wetland Supplement guidance have now been reported since the 1990-2019 Inventory submissions. Until the adoption of reporting using the Wetland Supplement guidance, only 1.3 Mt CO_2 equivalents of peatland emissions were included in the Inventory for the UK as a whole[29],because the methodology used to report national emissions is presently still using the IPCC 2006 methodology which did not appropriately capture emissions from peatlands. The known underestimate of globally reported peatland emissions prompted the production of the 2013 IPCC Wetland Supplement to address this issue. Work carried out for the UK Government Department for Business, Energy and Industrial Strategy[6] suggested a methodology to implement the 2013 Wetland Supplement, inclusive of UK-specific peatland emission factors and estimates of the currently underestimated emissions from peatlands across the UK. However, at the time of writing, this methodology has not yet been implemented in National Atmospheric Emissions Inventory reporting[6] . (UPDATE: This has now been superceded by the implementation into reporting). A refinement of the older 2006 IPCC Guidelines is also currently underway[30], which may introduce a few further changes in how emissions from

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[24] https://gallery.mailchimp.com/daf3c1527c528609c379f3c08/files/82234023-0318-408a-9905-5f84bbb04eee/Climate_Statement_2018.pdf

[25] https://www.ipcc.ch/site/assets/uploads/sites/2/2018/12/ST1.5_OCE_LR.pdf

[26] https://www.metoffice.gov.uk/binaries/content/assets/metofficegovuk/pdf/research/ukcp/ukcp-headline-findings-v2.pdf

[27] http://naei.beis.gov.uk/reports/reports?section_id=3

[28] https://www.ipcc-nggip.iges.or.jp/public/wetlands/

[29] Separate data for Scotland were not reported but can be obtained from the CEH LULUCF Inventory team.

[30] https://www.ipcc-nggip.iges.or.jp/home/2019refinement.html

land are accounted for. The current estimates[6] suggest that UK peatlands in good condition are net sequestering or at least net carbon neutral, while degraded peatlands are net emitting. UPDATE: A Defra-funded revision of emission factors for peatlands, inclusive of a move to AR5 for global warming potentials, has also been recently published, which still supports this statement[31] The long-term impacts of climate change on emissions from peatlands are not yet known. There are academic publications that suggest initially increased net sequestration until 2100[32], and some that assume peatlands even in good condition will soon become net emitting ecosystems[33]. This is a very active research area where there is no consensus yet, in part as feedback mechanisms are rarely included in models of future peatland functioning. It is also not yet fully established what the carbon consequences of second rotation woodland on peat soil under future climate may be. Finally, emissions from prescribed burning on organic soils (muirburn) are not yet fully accounted for in Inventory reporting. Although burning should not be carried out on peatland except where part of an SNH approved habitat management plan (Appendix 1), there is currently no monitoring in place for this and with future fire risks likely to increase under climate change, no means of predicting or monitoring inadvertent burning of peatland areas. UPDATE: A muirburn licensing scheme consultation is currently ongoing[34]

4.1.2 Biodiversity

The Nature Conservation (Scotland) Act (2004)[35] "places duties on public bodies in relation to the conservation of biodiversity, increases protection for Sites of Special Scientific Interest (SSSI), amends legislation on Nature Conservation Orders, provides for Land Management Orders for SSSIs and associated land, and strengthens wildlife enforcement legislation". sct

Policy in relation to peatlands is included within the wider 2020 Challenge for Scotland's Biodiversity (2013)[36], which takes into account the international Aichi targets agreed as part of the Convention on Biological Diversity in 2010[37] and the European Union Biodiversity Strategy published in 2011. The 2020 Challenge updated the previous strategy - Scottish Biodiversity Strategy; It's in Your Hands (2004), and both documents together constitute the Scottish Biodiversity Strategy. UPDATE: The Scottish Biodiversity Strategy to 2045 has been published since completion of this work[38].There are also further policy targets (sometimes

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31 https://sciencesearch.defra.gov.uk/ProjectDetails?ProjectID=21088&FromSearch=Y&Publisher=1&SearchText=peatland%20code&SortString=ProjectCode&SortOrder=Asc&Paging=10

32 https://www.nature.com/articles/s41558-018-0271-1

33 https://www.researchgate.net/profile/N_Fenner/publication/230743905_Drought-induced_C_loss_in_peatlands/links/0fcfd503ca0245d062000000.pdf

34 https://www.gov.scot/publications/wildlife-management-scotland-consultation/pages/5/

35 https://www.legislation.gov.uk/asp/2004/6/contents

36 https://www.gov.scot/publications/scotlands-biodiversity-route-map-2020; https://www.gov.scot/publications/2020-challenge-scotlands-biodiversity-strategy-conservation-enhancement-biodiversity-scotland/

37 https://www.cbd.int/sp/targets/

38 https://www.gov.scot/binaries/content/documents/govscot/publications/strategy-plan/2022/12/scottish-biodiversity-strategy-2045-tackling-nature-emergency-

implicit, rather than explicit) within Scotland's Forest Strategy, Scotland's Biodiversity Routemap, the Muirburn Code and Scottish Planning Policy (Appendix 1 for further details). There will be new targets that will need to be developed post 2020. Scotland has potential to make major contributions to e.g. the Sustainable Development Goal 15, which sets a target for 2030 to "combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral world"[39].

The current targets in the Scottish Biodiversity Strategy include implementing an ambitious peatland restoration programme that contributes to the EU/Aichi 15% area target for restoring degraded ecosystems; awareness raising amongst business for investment in natural capital, including peatlands; improving the condition of 80% of designated features to be in favourable condition; delivering focused action for priority species; and improve connectivity between habitats (Appendix 1 for further details). With the exception of the peatland restoration programme and statutory reporting on the condition of designated peatland habitats, there are no reporting mechanisms for the other targets or desired outcomes that are specific for peatlands.

A series of monitoring reports on the Scottish Biodiversity Strategy have been published, of which the most recent, covering 2014-2016, was published in July 2017[40]. This document only refers to peatlands for two core outcomes, in relation to ecosystem restoration and natural capital (Appendix 1, Big Steps 1 and 2). It highlights the ongoing programme of work carried out by Peatland ACTION in terms of spend and area where restoration activities have been carried out but doesn't summarise the benefits to biodiversity that restoration brings. There is currently no indicator for peatlands to assess delivery against the desired outcomes for Natural Capital beyond the site condition monitoring on designated areas. It makes reference to peatlands in the Natural Capital Asset Index, which has remained stable in part due to peatland habitats where condition was considered to be declining overall (on the basis of designated site monitoring[41]) and thus it appears that the biodiversity benefits of restoration on non-designated areas are not yet reported on within this framework.

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scotland/documents/scottish-biodiversity-strategy-2045-tackling-nature-emergency-scotland/scottish-biodiversity-strategy-2045-tackling-nature-emergency-scotland/govscot%3Adocument/scottish-biodiversity-strategy-2045-tackling-nature-emergency-scotland.pdf

[39] https://sustainabledevelopment.un.org/sdg15

[40] https://www.gov.scot/publications/scottish-biodiversity-strategy-report-scottish-parliament-2014-2016/

[41] The latest UK-wide update on trends in condition on peat forming Priority Habitats was the 2013 Habitats Directive Report (available online at http://archive.jncc.gov.uk/page-6387). This report suggests that, overall, all nine peatland habitat types under nature designation are currently in bad condition. Six of the peatland habitats were considered to show an overall improving trend in condition status. The majority of improving habitats, however, are fen type habitats, which occupy a relatively small proportion of the total UK peatland area. The condition of most bog habitats, including that of blanket bog, was declining. This is worse than suggested in the previous report published in 2007, and primarily due to changes (improvements) in methodology, but in one instance, for active raised bogs, a genuine decline in trend was identified. For non-designated areas, protocols are not harmonised.

Therefore, there appears to be significant potential to streamline current and future Biodiversity monitoring and reporting. Although not explicitly mentioned, other indicators and data sources do exist that could potentially be drawn upon to create peatland-specific baselines (Appendix 1) if the peatland specific components can be extracted. This will be discussed in more detail later in this report.

Peatland restoration and habitat management ambitions are also re-iterated in the IUCN UK National Committee Peatland Programme's Peatland Strategy 2018-2040[42], which sets a target for 2 million hectares of UK peatland in good condition, under restoration or being sustainably managed by 2040 (Appendix 1). Although not a formal UK umbrella strategy, it takes forward the 2013 Ministerial action statement on UK peatlands from the four devolved UK administrations and provides a co-ordinated focus covering all peatland types.

The devolved Governments contribute to mandatory country-level reporting under EU/global Biodiversity and Climate Change obligations and it these data that are compiled globally. The latest report from the FAO Global Peatlands Initiative[43] recommends collaborative actions across relevant institutions for international reporting on progress towards the Sustainable Development Goals (SDGs) under the United Nations Framework Convention on Climate Change (UNFCCC), the Ramsar Convention on Wetlands, the Convention on Biological Diversity, the United Nations Convention to combat Desertification and the Bonn Challenge on Forest and Landscape Restoration.

Q1. Is this an appropriate summary of the current and future key biodiversity and climate change policy requirements?

5. How are key terms such as peatland 'health', 'condition' and 'restored' defined in relation to policy targets?

Critical working definitions are required to address the preferred outcomes in the policy documents above. Appendix 2 discusses this in more detail, but, fundamentally, a discussion is required with regards to the key terms in existing definitions. Briefly, ecosystem 'health' definitions differ between that used in the 2020 Challenge for Scotland's Biodiversity and the more widely used Millennium Assessment[44] and a key differentiation is in whether the definition includes a requirement for the ecosystem to be able to 'carry out its natural function'. This could be a critical term as it could, for example, imply that a peatland that is stable and resilient to stress, but not (yet) a net peat accumulating ecosystem could not be considered to be 'healthy'. This definition affects both the assessment of baseline state for peatlands considered to be 'healthy' and the target for restoration and other management.

Similar potential conflicts arise with the term 'restored'. Peatland ACTION define their activities as putting peatlands 'on the road to recovery', which implies a trajectory towards

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[42] https://portals.iucn.org/library/node/47692
[43] http://www.fao.org/3/ca7233en/ca7233en.pdf
[44] https://journals.sagepub.com/doi/10.1177/0309133310365595

ecosystem health, rather than having achieved it. Such distinctions are critical in assessing success. In addition, it would be useful to define what constitutes restoration activity as opposed to ongoing management.

Q2. How should such key terms be defined?

6. Which potential condition indicators could be included in the monitoring framework?

Depending on the functional definition of condition, a set of potential indicators can be developed to monitor progress. However, how should indicators of health be structured? For the purpose of this report, we have defined these by ecosystem service, and ability to perform the required function, but it could equally be argued that they could be structured around other dimensions of e.g. sustainability and resilience. Under the currently established monitoring programmes, it is assumed that good or favourable condition equals a state where most required ecosystem services can be carried out, however this is not comprehensively tested. Neither is it clear whether current monitoring cycles allow for adequate assessments of sustainability and resilience. We discuss these dimensions in Sections 6 and 7 of this report. The future Peatland Monitoring Framework should aim to generate consensus around the dimensions of peatland 'health' that are required to appropriately assess indicators.

Q3. How should indicators be structured against the component parts of the 2020 Challenge for Scotland's Biodiversity definition (or an alternative) of peatland 'health' (Appendix 2)?

6.1 Potential indicators, using an ecosystem function-based framework

The 2020 Challenge for Scotland's Biodiversity (2013) identified the need for "spatial indicators of ecosystem health that operate at a national and regional level". The resulting current Scottish ecosystem health indicator framework (EHI)[45], established through the Biodiversity Science and Technical Group, includes a number of condition, function and resilience indicators, however it is currently limited to indicators that have already been developed. For peatlands, these include indicators on habitat extent and condition from the European Nature Information System (EUNIS) and the aforementioned Site Condition Monitoring reporting. As such, this indicator set is probably both too coarse and limited to the condition of sites under nature designation to function as an accurate measure of the overall health of Scotland's peatlands. There is also an indicator for terrestrial breeding

[45] https://www.environment.gov.scot/our-environment/state-of-the-environment/ecosystem-health-indicators/explore-ecosystem-health-indicators/

birds, but it is not disaggregated to peatlands. Finally, a static indicator of soil carbon content is currently included. Within the function indicator set, there are static functional connectivity maps for fen, marsh and swamp and heathland, and critical load exceedance maps for acidity and nitrogen, from which peatlands could be extracted. Under resilience indicators, the EHI lists ecosystem restoration, however the current dataset that is included does not specify actual areas of restoration or indeed its efficacy and instead reproduces the potential areas for restoration from the Carbon and Peatland 2016 mapping. The other three indicators, for non-native invasive species, emerging pests and soil sealing, are also suitable for extraction of peatland-specific metrics.

The currently included indicators in the EHI were only ever intended to provide a first attempt at assessing ecosystem health[46]. The expectation is that learning from their use, and with consideration or development of additional data sets, will permit future improvements to be made. In an EU and wider ecosystem-encompassing study, Maes et al (2016)[47] summarise and discuss the relative merits of several hundred candidate indicators of ecosystem health. We used a similar approach here. Table 1 lists potential indicators of peatland condition mapped to their respective ecosystem service.

Regulating services (water and climate regulation) are discussed first. Water regulation indicators are only assessed for the water storage component of peatland regulating functions as drinking water provisioning and flood protection were outside of the scope of this first scoping report. Two potential indicators could be identified for water storage in peatlands.

Peat soils contain the largest single store of terrestrial carbon. However, the climate regulating function of peatlands depends on their land use. Climate regulation is one of the most important ecosystem services both globally and on a European scale, but no indicators for this function have yet been developed. Table 1 gives details of nine potential indicators for climate regulation. Many of these require too much development and may not require direct reporting. For example, indicators for transfer of heat and moisture to the atmosphere, change in albedo, aerosol formation and microclimate regulation are likely to be influenced by other factors that can be monitored with other indicator sets, such as water table depth and its temporal fluctuations as well as topographical information. Evapotranspiration, albedo, aerosol formation and microclimate regulation are important factors that control the response of peatland to climatic variation and some are likely to influence not only greenhouse gas emission but also the survival of biota in peatlands. For example, peatland restoration has recently been noted to create locally cooler conditions[48], which could, in turn, influence survival of specialised peatland flora and fauna. Another indicator of peat carbon storage is the direct rate of peat accumulation, a Soil Formation (Supporting services) proxy. Net peat accumulation implies not only active carbon sequestration but also that the carbon store below is protected.

Biodiversity is assumed to be critical to the provision of ecosystem services – some assessments therefore class biodiversity as one of the ultimate delivery agents of all services

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[46] https://www.nature.scot/sites/default/files/2017-12/Guidance%20note%20-%20Ecosystem%20Health%20Indicators%20-%20%20May%202014.pdf
[47] https://www.sciencedirect.com/science/article/pii/S2212041615300504#s0090
[48] https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1029/2019JG005156

that an ecosystem can provide, rather than under any specific service. Others class biodiversity as a subclass of the supporting services (Table in Appendix 2) as the Millennium Assessment definition is that "Supporting services are those that are necessary for the production of all other ecosystem services"[49]. The IPBES framework[50] puts biodiversity into a different, intrinsically valuable, 'Nature' box – whereas ecosystem services sit within 'Nature's benefits to people'. Both approaches are equally valid. The current Scottish ecosystem health indicator framework, although it contains some condition indicators for land cover, protected site condition, bird populations, and a connectivity indicator, does not yet serve as a sufficient catalogue to monitor the full scope of intrinsic biodiversity. In all cases, the existing indicators are not specific to the full peatland area in Scotland, although some partial data may be extractable for peatland-specific condition and resilience indicators. There is no overall connectivity indicator for peatlands; although heathland and fen, marsh and swamp indicators exist. Table 1 lists the sixteen potential Supporting services or intrinsic nature/biodiversity values.

For each indicator, an assessment will also be needed to ascertain whether reporting needs to include spatial extent of the monitored indicators, and/or a definition of a state. For example, it is likely that a peatland monitoring framework will need capacity to address national targets as well as more local landscape- or site based evidence, such as levels of disturbance, and the extent of restoration. In order to test resilience, disturbance factors for peatlands will likely need to include monitoring of the extent of e.g. prescribed burning, drainage (old and new), development (energy, transport, housing), afforestation, tree/scrub encroachment, erosion, conversion to grassland and extraction. Restoration area indicators are not yet included in the current Scottish ecosystem health indicator framework, although this could be relatively straightforward to implement once spatial data from Peatland ACTION have been compiled. Some reporting has taken place in the most recent Climate Change Plan monitoring report[51].

Table 1. Core ecosystem services of peatlands that relate to water storage, climate regulation and biodiversity and potential indicators of their current state

Ecosystem services	Core ES proxy	Detailed description in:	Potential indicators
Regulating: water regulation (storage only as this affects GHG emissions*)	Site wetness	Appendix A5.1.	Site-based water table level

[49] https://www.millenniumassessment.org/documents/document.300.aspx.pdf
[50] https://www.sciencedirect.com/science/article/pii/S187734351400116X
[51] https://www.gov.scot/publications/climate-change-plan-monitoring-report-2018/pages/6/

Ecosystem services	Core ES proxy	Detailed description in:	Potential indicators
Regulating: water regulation (storage only as this affects GHG emissions*)	Site wetness	Appendix A5.2./3	Soil surface moisture content
Regulating: climate regulation	Carbon storage/ emissions	Appendix A5.4	Direct measurement of GHG emissions (chambers or flux towers) - CO_2, CH_4, N_2O, VOC
Regulating: climate regulation	Carbon storage/ emissions	Appendix A5.5	Direct measurements of losses of carbon in water courses (colour, DOC, TOC, POC and further conversion of these to CO_2/CH_4)
Regulating: climate regulation	Carbon storage/ emissions	Appendix A5.6a-e	Modelled GHG emissions of photosynthetic uptake and soil emissions, using remotely sensed parameters and ground observations
Regulating: climate regulation	Carbon storage/ emissions	Appendix A5.6 a-e	Vegetation proxies
Regulating: climate regulation	Carbon storage/ emissions	Appendix A5.7	Direct emissions of airborne losses of particulate carbon (erosion)
Regulating: climate regulation	Transfer of heat and moisture	Not assessed	Estimated evapotranspiration; land surface temperature from satellite
Regulating: climate regulation	Change in albedo	Not assessed	Vegetation/surface albedo
Regulating: climate regulation	Aerosol formation	Not assessed	Effects on solar radiation and cloud formation

Ecosystem services	Core ES proxy	Detailed description in:	Potential indicators
Regulating: climate regulation	Microclimate regulation	Not assessed	Measures of the complexity of local microtopography, influencing availability of shelter from heat, UV, wind and precipitation.
Supporting services: Soil formation	Peat accumulation	Appendix A5.8	Direct measures of C accumulation: Peat depth measurements, net ecosystem productivity, carbon content, bulk density; but corrected for surface motion
Supporting services: Provisioning of habitat (MA)/Habitats for species (TEEB)	Appropriate habitat condition	Appendix A5.9	CSM or analogous criteria for habitats that are still wetland or restored back to wetland.
Supporting services: Provisioning of habitat (MA)/Habitats for species (TEEB)	Appropriate habitat condition	Appendix A5.6a-e	Earth observations coupled with classification analysis or condition modelling
Supporting services: Provisioning of habitat (MA)/Habitats for species (TEEB)	Appropriate habitat condition	Appendix A5.6.a-e	Remote monitoring of new and historic disturbances (e.g. burning, drainage, development, peat extraction, erosion, grazing pressure)
Nature (Intrinsic values) IPBES	Appropriate (protected) species?	Appendix A 5.10.	Mammalian diversity and/or abundance
Nature (Intrinsic values) IPBES	Appropriate (protected) species?	Appendix A 5.10.	Amphibian diversity and/or abundance (e.g. frogs, toads)

Ecosystem services	Core ES proxy	Detailed description in:	Potential indicators
Nature (Intrinsic values) IPBES	Appropriate (protected) species?	Appendix A 5.10.	Reptile diversity and/or abundance (e.g. snakes, lizards)
Nature (Intrinsic values) IPBES	Appropriate (protected) species?	Appendix A 5.10.	Bird diversity and/or abundance (e.g. Farmland species abundance)
Nature (Intrinsic values) IPBES	Appropriate (protected) species?	Appendix A 5.10.	Other vertebrates' diversity and/or abundance
Nature (Intrinsic values) IPBES	Appropriate (protected) species?	Appendix A 5.10.	Invertebrate diversity and/or abundance (Arthropods, e.g. insects)
Nature (Intrinsic values) IPBES	Appropriate (protected) species?	Appendix A 5.10.	Invertebrate diversity and/or abundance (Molluscs, e.g. freshwater pearl mussel)
Nature (Intrinsic values) IPBES	Appropriate (protected) species?	Appendix A 5.10.	Invertebrate diversity and/or abundance (Annelids, e.g. earthworms)
Nature (Intrinsic values) IPBES	Appropriate (protected) species?	Appendix A 5.10.	Plant diversity and/or abundance
Nature (Intrinsic values) IPBES	Appropriate (protected) species?	Appendix A 5.10.	Lower plants and fungal diversity and/or abundance
Nature (Intrinsic values) IPBES	Appropriate (protected) species?	Appendix A 5.10.	Bacterial diversity and/or abundance
Nature (Intrinsic values) IPBES	Appropriate topography/connectivity	Appendix A5.6a-e	Landscape topography/connectivity

Q4. Have all potential indicator types been covered?

7. What protocols already exist for monitoring that can be deployed or adapted?

7.1 Reporting protocols

Beyond the statutory monitoring of nature designated sites, there is no off-the-shelf protocol to report on peatland condition indicators, either within Scotland, across UK peatlands, or internationally. Some indicators of peatland extent, condition and restoration, however, are currently embedded within wider reporting frameworks and therefore could be extracted and/or modified within a peatland-specific monitoring framework. The two examples that could be modified and combined with additional indicators are the Scottish Climate Change Adaptation Programme, which refers to some of the metrics for peatlands that are already in existence[52], and the Scottish ecosystem health indicator framework. Both of these frameworks combine individual component reports by using a common reporting style so that progress and outcomes for a range of indicators can be easily compared. A future national peatland monitoring framework could additionally include reporting compatibility with the National Performance Framework (Box 2) (UPDATE and the developing national Soil Monitoring Framework)[53].

Box 2. Indicators relating to peatland condition in the National Performance Framework

National Indicators with relevance to peatland monitoring for biodiversity and climate change outcomes:

- Access to green and blue space (Communities)
- Condition of protected nature sites (Environment)
- Index of abundance of Terrestrial Breeding Birds (Environment)
- Greenhouse gas emissions (Economy)
- Natural Capital Asset Index (Economy)

Q5: Are the SCCAP, National Performance and/or EHI reporting frameworks suitable models for the reporting within a future Peatland Monitoring Framework, are modifications required, or are there more suitable alternatives?

7.2 Indicator types

Indicators of peatland condition include those that define the current or baseline state (state indicators), and those that inform about change (change indicators). There are also

[52] https://www.climatexchange.org.uk/media/1372/cxc_adaptationguide_hyperlinks.pdf

[53] https://www.parliament.scot/chamber-and-committees/questions-and-answers/question?ref=S6W-02084

requirements to report on loss and damage. For the purpose of this scoping report, we carried out an online survey amongst major stakeholders that asked for their perception on the readiness of the indicators in Table 1 to be used for a variety of purposes including state, change, early warning and loss and damage reporting. The full results are available in Appendix 6, Table 1 and the questionnaire itself in Appendix 6.3. Of those potential state indicators that have been identified, few currently are sufficiently developed for a national monitoring framework, with the exception of the currently used suite of statutory and analogous site condition monitoring indicators (Table 2).

Table 2. Current level of availability of different indicator types, based on information provided by survey respondents. C- currently available; P-potential for development; x-not feasible; ? – uncertain. Table condensed to indicators with survey returns only (Appendix 6).

Potential indicators	Baseline indicator (i.e. those still to be developed)	Existing indicators (change/trends)	Indicators for sustainability of current management	Indicators as early warning of change	Indicators for loss and damage reporting
Site-based water table level	P	P	P	?	X
Soil surface moisture content	P	P	P	?	X
Surface oscillation	P	P	P	P	P
Direct measurement of GHG emissions	P	P	P	P	X
Direct measurements of losses of carbon in water courses	P	P	P	P	X
Modelled GHG emissions, using remotely sensed parameters and ground observations	P	P	P	P	X
Vegetation proxies	P	P	P	P	?
Direct measures of C accumulation	P	P	x	?	?

Potential indicators	Baseline indicator (i.e. those still to be developed)	Existing indicators (change/trends)	Indicators for sustainability of current management	Indicators as early warning of change	Indicators for loss and damage reporting
CSM or analogous criteria for habitats that are still wetland or restored back to wetland.	C	C	C	C	C
Cover of a specific functional group of vegetation (e.g. Sphagnum cover, extent of bare peat	P	P	P	P	P
Earth observations coupled with classification analysis or condition modelling	P/C	P	P	P	P
Monitoring of new and historic disturbances (e.g. burning, drainage, development, peat extraction, erosion, grazing pressure)	P	P	x	x	P

7.3 Monitoring protocols and technologies

The majority of indicators are measured with various protocols (i.e. there are no harmonised, standard, protocols, Appendix 5.1-10) and almost all are currently monitored for research purposes only and therefore not used to report on national scale peatland condition. In almost all cases, results are compared to local reference states, which means results cannot be readily compared between sites or regions. The following sections explore the individual indicators in Table 2 full.

7.4 Water storage indicators

Water storage is one of the critical ecosystem services peatlands provide (Table 1). A crucial indicator in this regard is a measure of the water table in relation to temporary or permanent state changes. Such a measure is also of high value for any potential future method development for emissions from peatlands under the other land use/land cover categories, since models of peatland carbon dynamics invariably require water table depth as a critical input (e.g. Waddington et al., 2015; Smith et al., 2007[54]). Both the temporal and spatial aspects of water level monitoring require further development. Water level monitoring frequencies in the literature ranges from sub-hourly (automatic) to campaign-based (manual). There has been no review that has determined the optimal measurement interval. A basic requirement for an area to be defined as rewetted/restored would require estimates of the zone of influence of the management, such that only areas that have been hydrologically altered as a direct influence of the management are accounted for. This invariably requires some assessment of the state prior to management intervention and is one of the most critical datasets lacking at national level at present. Other guidance in relation to peatland monitoring programmes such as the Natural England Guidelines for monitoring peatland restoration[55] [19] and the associated review of monitoring techniques[56] already identified the ideal scenario as establishing baselines prior to intervention, however this has not been carried out in the past and this scoping report will therefore also consider methods that may allow retrospective modelling of water table depths. Defining success of restoration or management efforts to improve condition in terms of water storage may not be possible in terms of a single desired outcome, as the hydrological balance of a given peatland site is spatially determined by climatic, site-specific environmental factors (e.g. slope(s), aspect) and the impact of the human intervention. Therefore, multiple outcomes may exist, where, using a simplistic example, rewetting efforts on sites with minimal drainage in areas of high rainfall and low evapotranspiration have a lower impact on site hydrology than on sites with high degrees of drainage in areas of lower rainfall and/or low evapotranspiration. Interannual differences in rainfall patterns and air temperature can further complicate efforts to define a single water table-depth reference state. The current UK climate change projections may limit options for particular outcomes[57] and therefore water table depth monitoring should take into consideration that there are regional differences in the predicted changes and design a monitoring framework with this in mind. Water table monitoring, depending on the time interval across which measurements are taken, may be able to integrate other information on condition, for example water table depth monitoring with automatic loggers can provide data on stress resilience as well as being a good indicator of restoration progress (Appendix Table 6.1). There is currently a good coverage of sites across Scotland, but data have not yet been analysed to test whether water table depth monitoring provides a useful condition indicator at national scale (Appendix 5.1). Site wetness indicators are not yet developed enough to be used in a monitoring context (Appendix 5.2-3). UPDATE: Since completion of this work, the usefulness of water table dept as a proxy of carbon dioxide and methane emissions has been established to be robust across continental scales[58].

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[54] Smith et al (2007) ECOSSE *Estimating Carbon in Organic Soils - Sequestration and Emissions* Final Report. http://nora.nerc.ac.uk/id/eprint/2233/

[55] http://publications.naturalengland.org.uk/publication/24008

[56] http://publications.naturalengland.org.uk/publication/46013

[57] https://www.metoffice.gov.uk/research/collaboration/ukcp

[58] https://www.nature.com/articles/s41586-021-03523-1#citeas;

7.5 Carbon storage / Emissions indicators

Another key indicator of peatland health is the establishment of an active vegetation layer and peat surface layer (acrotelm) that is able to sequester carbon as per their natural climate regulation function. As per earlier sections, this not only includes direct emissions of the major greenhouse gases (CO_2, CH_4 and N_2O) and emissions of these arising from oxidation of particulate and dissolved organic matter in peatland streams, but also interactions with other greenhouse gases. For simplicity we omit water vapour itself, however, there are potential scientific needs to better understand the impacts of elevated ozone concentrations on peatland carbon cycling (especially net methane production)[59]. As per the water storage function, a single outcome (such as a certain level of net carbon sequestration) may not be realistically achievable and a monitoring programme will need to assess the likely multiple, spatially structured, outcomes across Scotland. This monitoring programme could also aid the development of country-specific emission factors for peatlands under different land cover, which is presently still in development due to a relative lack of data[60],[61]. The net production of carbon dioxide, methane and nitrous oxide are governed by climatic, site environmental, and management factors via modulation of the water table and creation of soil environments) that favour particular biogeochemical pathways over others. The crucial characteristic, however, is whether a new stable state, indicative of lower net emissions, and ideally, close to zero net emissions, can be achieved. As with water storage indicators, there has been no review of the spatial or temporal data requirements to adequately assess condition.

The UK has national commitments under the Climate Change Act and international commitments under the UN Framework Convention on Climate Change to reduce net GHG emissions and is under statutory obligation to report annually. The UK GHG Inventory does not yet fully incorporate the emissions and removals on peatland areas, although a BEIS-funded project to implement the methodology set out in the 2013 IPCC Wetland Supplement (WS)[62],[63],[64] has recently completed a draft methodology. There are key uncertainties around the implementation of the 2013 IPCC Wetland Supplement. These are examined in more detail in Appendix 3.

It will need to be assessed whether the transfer times used in the UK GHG Inventory (25 years to move from one category to another, i.e. from rewetted to near-natural) are

[59] https://meetingorganizer.copernicus.org/EGU2018/EGU2018-19139.pdf
[60] https://www.theccc.org.uk/wp-content/uploads/2018/11/Quantifying-the-impact-of-future-land-use-scenarios-to-2050-and-beyond-Full-Report.pdf
[60] https://www.theccc.org.uk/wp-content/uploads/2018/11/Land-use-Reducing-emissions-and-preparing-for-climate-change-CCC-2018-1.pdf
[61] https://www.theccc.org.uk/wp-content/uploads/2017/04/Quantifying-Greenhouse-Gas-Emissions-Committee-on-Climate-Change-April-2017.pdf
[62] https://www.theccc.org.uk/wp-content/uploads/2018/11/Quantifying-the-impact-of-future-land-use-scenarios-to-2050-and-beyond-Full-Report.pdf
[63] https://www.theccc.org.uk/wp-content/uploads/2018/11/Land-use-Reducing-emissions-and-preparing-for-climate-change-CCC-2018-1.pdf
[64] https://www.theccc.org.uk/wp-content/uploads/2017/04/Quantifying-Greenhouse-Gas-Emissions-Committee-on-Climate-Change-April-2017.pdf

appropriate, or whether they would introduce an overly optimistic estimate of achieved mitigation. Compatibility of the emission factors used also needs to be assessed between the various delivery/reporting instruments (Peatland Action, Peatland Code) and the UK GHG Inventory.

For some of these methods, it will be critical that reporting of the areas matches the definition in the relevant reporting instrument. For example, there is a need for area reporting of 'restored' areas to match the reporting in the Inventory, where the current terminology for this category is 'rewetted', in line with the IPCC Wetland Supplement[65]. Similarly, restoration of three-dimensional landscape needs to be reported in the same way that the UK GHG Inventory treats the UK total land area, otherwise there is a danger of over-reporting, if, for example, restoration area estimates in eroded ecosystems include a 3D estimate of the surface area. However, this may also introduce a major bias against restoration of such challenging areas, as the cost-effectiveness of this type of management may appear to be low.

Direct monitoring of greenhouse gas emissions was considered to be desirable by our survey respondents (Appendix Table 6.1), as the major indicator of condition from a peat accumulation and net emissions perspective, however the cost of monitoring is prohibitive beyond use for selected sites. There is, however, scope to use such data to parameterise approaches that utilise Earth Observations (EO), with some progress already existing in monitoring the photosynthetic fixation of carbon dioxide (gross primary photosynthesis, GPP) via EO proxies. It may also be possible to develop an umbrella programme such as first recommended by the JNCC (2011)[66], tied into development of a EO-based monitoring and modelling approach and which could include a tiered monitoring system with the highest level of monitoring based on full eddy covariance on-site monitoring and lower tier sites utilising lower cost options based on longer-term peat accumulation and/or subsidence monitoring.

7.6 Habitat condition and (protected) species indicators

Vegetation monitoring outside of existing habitat condition monitoring schemes, in particular, uses a multitude of approaches, with resulting data that are not comparable to each other (further discussed in Appendix 4). Surface oscillation as measured using interferometric synthetic aperture radar (inSAR) is considered as a potentially very powerful integrative indicator of site condition (Appendix Table 6.1), however it still needs to be tested at national scale (a 'Bog Breathing' project funded by SNH is currently ongoing to address this; UPDATE The first report arising from this work is now published and suggests that this could be a very valuable remotely sensed indicator of peatland condition[67]). Similarly, mapping of peatland vegetation types is feasible from EO data, but there have not yet been many reports on how this could be expanded to monitor condition in detail.

It is in establishing whether a site fulfils the criteria of ecosystem health in relation to its supporting biodiversity functions, that defining uccess becomes very difficult. One option is

[65] https://www.ipcc-nggip.iges.or.jp/public/wetlands/
[66] http://archive.jncc.gov.uk/pdf/jncc443_web.pdf
[67] https://www.nature.scot/satellites-track-bog-breathing-help-monitor-peatlands

to focus on resilience as an inherent property, where the defining characteristic is of an ecosystem in a self-sustaining state[68]. In simple terms, monitoring approaches measure such change using either comparison with reference states (before - after -control - intervention, BACI designs) or trajectory analysis away from the starting condition and towards a desired state[19]. In peatland systems, a restored peatland control reference state would be a nearby site with no human influence. This is often not available and therefore, the second option is often the only workable solution, where success is defined as achievement of a new system state that is different to the starting condition and more like that of a natural bog or fen ecosystem. However, as mentioned, there may not be a single potential outcome and trajectory-type analyses in particular can also identify whether a system enters an alternative stable state that is not typical of a bog or fen.

Whilst it may be feasible to track progress towards a new, stable, state; an assumption that the desired outcome is, for example, a blanket bog ecosystem state in good condition as defined by the Common Standards Monitoring framework[69], may not be realistically achievable within the timelines of the policy targets. One of the key criteria for assessment, for example, is that at least 6 indicator species should be present (Box 3). This may not be a realistic outcome within a decade or less, even where habitat conditions are suitable for re-establishment, if there are limited options for dispersal from nearby donor sites.

Box 3. Excerpt of indicator species for blanket bog (from JNCC CSM Guidance for Uplands)[22]

Table 1. Indicator Species				
Andromeda polifolia	*Cornus suecica*	*Eriophorum vaginatum*	Non-crustose lichens	*Sphagnum* spp.
Arctostaphylos spp	*Drosera* spp.	*Menyanthes trifoliata*	*Pleurocarpous* mosses	*Trichophorum cespitosum*
Betula nana	*Erica* spp.	*Myrica gale*	*Racomitrium lanuginosum*	*Vaccinium* spp.
Carex bigelowii	*Empetrum nigrum*	*Narthecium ossifragum*	*Rubus chamaemorus*	
Calluna vulgaris	*Eriophorum angustifolium*		*Rhynchospora alba*	

This issue becomes even more pressing for biota that are currently understudied and where no target state for peatland habitats supporting them exists (e.g. invertebrates). Such imbalances in existing definitions of potential target states may introduce bias towards more easily achievable targets. In other words, whether we are aiming to have healthy peatland systems as per the Millennium Assessment ("if it is stable and sustainable—that is, if it is active and maintains its organization and autonomy over time and is resilient to stress") or one that, per 2020 Challenge "retains its natural functions", these states are generally not definable for a large number of taxa due to a paucity of data. This means that our current monitoring efforts, being relatively blunt instruments, are only able to detect state shifts in certain ecosystem service categories.

Q6: Is this an adequate description of those indicators that could be relatively straightforwardly adapted, and have the critical elements that are required to do this been raised?

[68] https://besjournals.onlinelibrary.wiley.com/doi/full/10.1111/1365-2664.12550
[69] http://jncc.defra.gov.uk/pdf/CSM_Upland_jul_09.pdf

8. Which indicators may require further method development?

Several indicators are not currently sufficiently developed to allow for monitoring of critical elements of peatland net emissions monitoring. For examples, the IPCC Wetlands report recommended further work on establishing emissions derived from the losses of particulate organic carbon (POC), dissolved organic carbon in water courses (DOC) and nitrous oxide emissions (both direct and indirect). Most of the indicators of intrinsic nature beyond protected species monitoring are underdeveloped or non-existent, and there is as yet no established method to monitor trophic interactions. There are also currently no indicators for landscape topography or connectivity, which could help our understanding of longer-term changes in plant and animal populations, and indirectly, microclimate regulation. Although water level monitoring is relatively established, there is not yet a developed indicator for soil surface moisture content, which could function as both an indicator of site wetness and water storage capacity but also link to climate regulation function indicators such as transfer of water vapour. There are also no existing indicators of changes in albedo or heat regulation, which could be relatively straightforwardly developed using Earth Observations.

Loss and damage indicators, in particular, require further development as a whole; the focus at present is mostly on baseline indicators and monitoring for longer-term change rather than damage events such as loss or damage of peat through development, land use conversion or fire.

Q7: Are there any other aspects of indicator method development that have not been addressed?

9. How critical is it to agree appropriate monitoring timeframes for each indicator?

Timelines and reporting intervals currently vary amongst the various existing policy commitments, however there are some commonalities. For example, both the UK GHG Inventory submission and the wider Climate Change Plan monitoring interval are on an annual basis, whilst reporting on the implementation of the Scottish Biodiversity Strategy is on a three-yearly period. Peatland greenhouse gas emissions monitoring is still relatively ad hoc given that peatland emissions are currently still accounted for using 2006 IPCC guidelines (except forestry on peat). The scoping report on how to implement the 2013 IPCC Wetland Supplement methodology in reporting highlighted considerable data gaps in our understanding of emissions from UK peatlands and therefore some of the proposed emission factors for inclusion in the UK GHG Inventory had higher uncertainties than others

(Evans et al., 2017[70]). This suggests that additional effort in monitoring greenhouse gas emissions from peatlands is required in order to ensure more accurate national level accounting. Such additional monitoring efforts would require two considerations with regards to data quality:

The first consideration is around the frequency of measurements in relation to data quality (A.5.4.). Chamber-based monitoring often overestimates emissions as night-time fluxes are rarely measured, or not fully accounted for in the calculation of the annual net emissions. Eddy covariance-based monitoring has the advantage of being continuous throughout the year, and generally returns high quality data, but requires expensive infrastructure, specialised expertise in running the equipment and the site has to be relatively flat (A.5.4). A second consideration is regarding the length of time measurements should continue for. Peatland net emissions are determined by the delicate balance between net uptake of carbon by e.g. the vegetation and net loss of carbon from decomposition processes. Even in a near natural peatland, there is variation between years, and climatic conditions in some years, e.g. a summer drought, can cause occasional years of net emissions rather than the expected net sequestration. It would therefore be useful to agree on common guidelines for frequency and duration of emissions monitoring.

Similar considerations apply to water table monitoring, which ranges from automated (every 30 minutes or more frequent) to manual, sporadic, measurements. More frequent measurements are more likely to pick up critical differences in behaviour during periods without rainfall, and therefore consensus on the best measurement frequency should be sought. Similar to emissions monitoring, water tables fluctuate in accordance to climatic conditions in any given year and so the monitoring framework should give consideration to the likely required duration of any water table monitoring components.

There is currently only one dataset/methodology that is used as both a baseline and change indicator of peatland habitat condition in a formal reporting framework – the Common Standards Monitoring dataset collated by JNCC and which is used to report UK Habitats under Article 17 of the EU Habitats Directive. The latest UK-wide update on trends in condition on peat forming Priority Habitats that used this methodology was the 2013 Habitats Directive Report[71], the third such 6-yearly report. Analogous methods to those in the Common Standards Monitoring are being used by initiatives that aim to monitor peatland condition on non-designated land, such as RSPB's Habitat Monitoring Scheme, but their usefulness has never been tested against the sensitivity of the Common Standards Monitoring data. None of the other indicators have a sufficiently robust standard methodology, nor have they been sufficiently validated, to serve as indicators in a national framework at present. The only example of a baseline indicator of peatland condition that is currently truly national (i.e. not extrapolated from designated site monitoring) is a research product that modelled condition across the whole Scottish peatland area using long-term observations from the MODIS satellite with training data for the model from the Common

[70] https://uk-air.defra.gov.uk/assets/documents/reports/cat07/1904111135_UK_peatland_GHG_emissions.pdf

[71] http://archive.jncc.gov.uk/page-6387

Standards Monitoring. However, this work could not be fully validated against a sufficient number of compatible, independent, ground observations.

Length of monitoring in restoration programmes is something that will require recommendations to be formalised. At present, there is no single UK peatland restoration project that has demonstrated full recovery[72]. The oldest of these monitored projects are now around 20 years since restoration began, but these were often very heavily disturbed to begin with and, additionally, were initially restored primarily for biodiversity objectives. A future Peatland Monitoring Framework should include guidance on monitoring intervals and longevity of monitoring programmes on restoration sites. It is possible that monitoring may need to extend beyond current policy target timelines, i.e. beyond 2045-50.

Q8: Are there any other critical points that have not been raised on monitoring timeframes?

10. How can the appropriate spatial sampling density be estimated for each indicator?

National level reporting needs to be able to cover all peatland habitat types (for biodiversity reporting), damage categories (for UK Greenhouse Gas Inventory reporting) and climatic zones (for future risk assessments). In addition, restoration sites need to be monitored for progress, and the framework needs to be able to identify likely loss and damage. Within each of these, there also needs to be an appropriate depth of sampling to allow robust estimates of condition to be made. As an example, a recent attempt to estimate the proportion of peatland affected by drainage, a sampling size of 330-400 blocks of 500 m assessed using aerial photography was sufficient to return a reasonably robust estimate of drainage proportion[73]. A formal monitoring framework will need to assess the minimum number of monitoring locations required to produce robust data. It would be useful to assess the variability of existing datasets, for example the water table depth monitoring carried out within Peatland Action, in relation to climatic variation but also previous land use or restoration techniques. Once suitable sampling density is agreed, there are spatial statistical methods that can be used to inform on suitable monitoring locations, e.g. conditioned Latin hypercube sampling.

A second component relating to spatial density of sampling relates to the extent to which the actual condition on the ground is measured. There is invariably a trade-off between assessments that gather very precise data at specific locations, and those that integrate at larger spatial scale. For example, water table monitoring in dipwells is only indicative of the water table at the specific point of measurement and so there may need to be a minimum, nested, number of measurements within each site for certain indicators that has to be

[72] https://www.iucn-uk-peatlandprogramme.org/resources/commission-inquiry/commission-inquiry-peatlands-update-2017-19

[73] https://www.climatexchange.org.uk/media/1483/comparison_of_remote_sensing_approaches_for_detection_of_peatland_drainage_in_scotland.pdf

decided upon. Existing monitoring frameworks recognise this; in Common Standards Monitoring, there is a requirement for a minimum number of point-based assessments that is dependent on the size and complexity of the individual site. In this methodology, if a site is deemed to have failed to meet the standards for favourable condition there needs to have been failure to meet the criteria at multiple sampling points. In Earth Observation-based monitoring, coverage will be easier to address, but it is as yet unknown whether this approach offers a suitable resolution to pick up trends in condition. In greenhouse gas emissions monitoring, modelling of Earth Observations is not yet able to represent net emissions. On the ground monitoring approaches tend to be either point-based measurements using chambers, which require the same nested approach for upscaling, or eddy covariance-based monitoring which covers a footprint ranging from around 200 m^2 to several km^2 depending on the terrain and the height of the instrumentation. Eddy covariance measurements will be more easily comparable with Earth Observations and, globally, there has been significant effort to develop models that utilise these data sources. The merits and demerits of on-site measurements for the various indicators against those that Earth Observations can provide will therefore require to be assessed further and a consensus sought on the spatial resolution offered by, and required density of sampling locations for, each individual indicator.

Q9: Have all critical elements of the spatial aspects of a future framework been raised?

11. What are the strengths, weaknesses, opportunities and threats of potential identified indicators and what gaps remain?

11.1 Strengths, weaknesses, opportunities and threats

We gathered views on strengths, weaknesses, opportunities and threats of potential identified indicators from the previous workshop's participants. Appendix Table 6.2 compiles the SWOT analysis returns from the survey. As mentioned previously, the number of returns was rather low, and therefore the analysis is incomplete at present. The same themes were present as in earlier section of this report: the majority of the datasets collected to date showed significant strength as local indicators, and potential to be useful as indicators of peatland condition at national stage, but the vast majority of these had not been analysed for this purpose and therefore conclusions with regard to their usefulness as national scale indicators would be premature. Significant opportunities were assumed in the development of models using EO data, however all these still require further development, and in most cases, a standardised manner of generating resolution-compatible ground observations. Most threats identified were in relation to future funding sources to maintain existing data collections, and/or in funding availability with regard to further development work. In relation to monitoring using Earth Observations, a specific threat was perceived in relation to data accessibility (currently free).

Q10: Does the SWOT analysis in Annex Table 2 cover all relevant points?

11.2 Gap analysis

The Climate Change Plan indicator (area of restored peatland on the road to recovery) does not yet have a standard monitoring method to determine the area restored. Whilst data on intended rewetted area are collated from the application forms to Peatland Action, there is no formal method to assess the actual area restored on the ground at present. With line features such as drains that are being blocked, it is also difficult to define what area has been subsequently restored. This should be urgently addressed. The process-based indicators in relation to peatland restoration within the Climate Change Plan are more straightforwardly addressed, and a reporting framework for this is in existence within Peatland Action (this is in development, Pers. Comm: Lucy Allen, NatureScot).

Emissions targets reporting has yet to be defined for peatlands. There are some considerable evidence gaps in our understanding of current emissions from degraded peatlands and a carefully designed emissions monitoring component in the framework could fill them. For example, there are major data gaps for non-gaseous emissions that convert to CO_2 and CH_4, i.e. DOC and POC. Even for direct gaseous emissions of CO_2, CH_4 and N_2O, there are major data gaps for certain land use types, for example from eroded, drained, or afforested peatlands and from peatland converted to extensive grassland. Losses of carbon through fire on peatland habitats, whether managed (muirburn) or wildfire, also still constitute a major evidence gap in the UK emissions reporting.

Biodiversity monitoring largely concentrates on vegetation-only monitoring; however, this only fulfils part of the EU Habitats Directive requirements, e.g. it doesn't address Annex II/IV species monitoring. Scotland's Biodiversity Routemap targets in relation to the condition of designated peatland sites can be reported on using existing frameworks. Habitat condition monitoring is harmonised across designated sites, but the framework is currently under review. There is currently no mechanism to assess habitat condition on other peatland areas. There are various pilot monitoring projects that show potential to collect monitoring data on peatland condition across the whole of the national resource, using both optical satellite data sources from e.g. Sebtinel-2, Landsat, and MODIS, and radar technology via interferometric and standard synthetic aperture radar. However, the majority of these technologies have not yet been fully tested in a national reporting context. Our work was unable to assess gaps in reporting towards the "Delivering focused action for priority species" aim, as we did not receive survey returns that elaborated on existing or potential reporting mechanisms.

Data on land use conversions (Loss and Damage indicators) can be difficult to find and most data for Scotland are out of date. There is an indicator of development (soil sealing) but data would require to be extracted for peatland. Indicators for land cover conversion are at present limited to mapping by major habitat type, which would realistically only cover conversion to grassland. Afforestation of peat soils can be extracted from the annually updated National Forest Inventory. Extraction is mapped by the LULUCF Inventory team as this is a statutory requirement for the UNFCCC annual UK GHG Inventory submission, however it is unclear as to whether the data are accurate. There is currently no mapped product of prescribed burning, drainage, tree/scrub encroachment or erosion as the last time these were mapped at national scale in Scotland was for the Land Cover of Scotland 1988 (LCS88). For some of these categories, there have been limited efforts to map these using Earth Observations (Appendix 5.6.a-e).

Some 'Loss and Damage' indicators have not been explicitly addressed to date, for example, muirburn, deep fire; windfarm drainage (present alongside offsetting with associated restoration) and soil sealing (turbine bases, roads, tracks) have not been mapped at all or not since the LCS88. Some data on windfarm construction could possibly be extracted from OS mapping sources (turbine bases and access roads). SEPA may have data related to >50MW installation planning documents but there is micrositing allowed at construction stage. There are uncertainties over peat depths at turbine bases and therefore the volume of peat extracted and/or lost during construction. Windfarm repowering can create a fragmented peatland landscape, and additionally confers no requirement to restore peat below 1 m in depth. Conversely, an assessment of if/when forestry blocks and windfarms on peat will come on stream for 'decommissioning' could be a useful planning exercise.

There is currently insufficient information on requirements for data storage/access/sharing with other parties that may require peatland monitoring data (e.g. UK GHG Inventory team). This makes it difficult to assess structural elements of a future peatland monitoring framework. Similarly, lack of clarity on the required spatial extent for reporting at this stage precludes an analysis of how sufficient sampling depth could be obtained. However, there are established methods, e.g Latin hypercube approach etc., once this has been finalised.

Finally, given the many uncertainties, we were unable to estimate the cost aspects of any future monitoring programme. However, future estimates of costs should include costs for underpinning capacity required, such as training data collection for modelling, as well as the maintenance sampling costs once the programme has been established.

Q11: Have all data gaps been appropriately addressed?

11.3 Ways forward

This report was prepared as a first step to open up dialogue about possible options for the national peatland monitoring framework amongst stakeholders. We concluded each section with questions which could be used to gather written feedback during a formal consultation phase, which could, in turn, be used to update this report. A follow-up phase that involves stakeholders to develop recommendations should then be feasible. A national peatland monitoring framework will likely require to be integrated with other frameworks. Therefore, common outcomes should be considered, e.g. the Scottish Government's National Performance Framework also includes a number of National Outcomes that relate to peatland area and condition, notably in the Communities, Economy and Environment Outcomes (Box 2). It could also be considered whether peatlands could be reported separately within the National Capital Asset Index (NCAI) in future. Peatlands are under ecosystem restoration (10) at present. This may not be a high priority at present, but a well-designed Peatland Monitoring Framework could lay the foundations for future inclusion.

Q12: Is the proposed use of this document as a basis for stakeholder discussion supported?

12. Appendix 1: Legislation and Policy Instruments

Table 1. UK and Scotland policy targets in relation to peatland biodiversity and GHG emissions.

Critical phrases requiring working definitions in bold.

Policy document	Aims/Targets	Policy output indicators	Delivering organisation and deadlines
Climate Change Plan (page 182 – Ambition; page 185 - Indicators) UPDATE: This is now superceded by the Update to the Climate Change Plan 2018-2032 (see text)	To make progress towards this ambition, we will focus on achieving a significant increase in the scale of degraded peatland restored, from a 1990 baseline to: • 50,000 hectares **restored** by 2020 • 250,000 hectares **restored** by 2030 Our longer-term ambition is that by 2050, Scotland's expanded peatlands will be **thriving** habitats and sustaining a diverse ecosystem. Policy outcome 1: To enhance the contribution of peatland to carbon storage, we will support an increase in the annual rate of peatland restoration, from 10,000 hectares in 2017-2018 to 20,000 hectares per year thereafter.	2020) Number of hectares of **restored** peatland per year Implementation indicators: 2020) Number of hectares **on the road to recovery** through Peatland Action at the conclusion of the preceding financial year. 2) Total number of applications received for Peatland Action restoration project funding. 3) Number of projects approved for funding from the Peatland Action restoration project funding. 4) Number and area of restoration feasibility plans supported through the Peatland Action programme.	Peatland Action (SNH) 2020, 2030, 2050
Scotland's Forestry Strategy 2019-2029[74] (page 24); referring to UK Forestry Standard[75], page 44; 54.	Avoid establishing new forests on soils with peat exceeding 50 cm in depth and on sites that would compromise the hydrology of adjacent bog or wetland habitats. Note: Woodland creation on certain sites where deep peat soils have historically been highly modified may be considered, provided that it complies with the relevant country policy.	None identified	Scottish Forestry no specific deadline

[74] https://www.gov.scot/publications/scotlands-forestry-strategy-20192029/
[75] https://www.forestry.gov.uk/pdf/FCFC001.pdf/$FILE/FCFC001.pdf

Scotland's Biodiversity Routemap, page 13; 17; 2020 Challenge for Scotland's Biodiversity; page 8, UPDATE: This is nw superceded by the Scottish Biodiversity Strategy to 2045 (see text)	Big Step 1: Ecosystem Restoration 2020 Challenge Outcome: Scotland's ecosystems are **restored to good ecological health** so that they provide robust ecosystem services and build our natural capital. Priority Project 1: Restoration of peatlands *Aim:* **Restore** peatland condition and function in order to generate benefits through ecosystem services; carbon sequestration, carbon storage, water quality, flood management and more abundant nature. *Target:* Ambitious peatland restoration programme underway, contributing to the EU 15% degraded ecosystem restoration target. Big Step 2 – Investment in Natural Capital 2020 Challenge Outcome: Natural resources contribute to stronger sustainable growth in Scotland, and we increase our natural capital to pass on to the next generation. Priority Project 4: Securing economic and social benefits from, and investment in, natural capital *Aim:* Economic and social benefits from improving Scotland's natural capital are demonstrated, and investment secured through new or existing instruments. *Target:* Businesses are more aware of their reliance on Scotland's natural capital, and more investment is being made in building natural capital. Big Step 4 – Conserving wildlife in Scotland Outcome 4: The special value and international importance of Scotland's nature and geodiversity is assured, wildlife is faring well, and we have a highly effective network of protected places. Priority project 8: At least 80% of designated features in **favourable condition** by 2016. Priority project 9: Delivering focused action for priority species	No peatland-specific indicator developed yet for Outcome 1. Developing the Peatland Code[76] as a framework for investing in peatland restoration. Developing the Natural Capital Asset Index (NCAI) [77]as a means of assessing Scotland's natural capital and the sustainability of the Scottish economy. (Peatlands are given particular emphasis because of their vital role in storing carbon and thereby contributing to a low carbon economy, and also because of their international conservation importance) Abundance of terrestrial breeding birds[78] Wintering waterbirds[79]; national plant monitoring scheme[80]; terrestrial insect abundance (specialist and generalist butterflies; moths)[81],[82]; Notified species/notified habitats in favourable condition (Site Condition Monitoring[83]); National Biodiversity Network Gateway[84], displayed in Scotland through the NBN Atlas Scotland[85]) Breeding Farmland Birds[86] (for peatlands converted to grassland or cropland)	SNH, 2020

Policy document	Aims/Targets	Policy output indicators	Delivering organisation and deadlines
	Big Step 5: Sustainable management of land and freshwater Outcome 5: Nature is faring well, and ecosystems are **resilient** as a result of sustainable land and water management. Priority project 10: Improve connectivity between habitats Priority project 11: Promotion of measures to support biodiversity under CAP. A suite of sites demonstrating good practice aimed at supporting wildlife. Outcome 7: A framework of indicators that we can use to track progress.	Wildlife Estates Scotland Initiative and demonstration farms A set of ecosystem health indicators[87]; SEWeb, the National Biodiversity Network (NBN) and Biodiversity Action Reporting System (BARS)[88]	

[76] http://www.iucn-uk-peatlandprogramme.org/peatland-code
[77] https://www.nature.scot/professional-advice/planning-and-development/valuing-our-environment/natural-capital-asset-index
[78] https://www.bto.org/news-events/news/2018-11/scottish-terrestrial-breeding-bird-indicator
[79] https://www.nature.scot/sites/default/files/2018-09/Scottish%20Biodiversity%20Indicator%20-%20S004%20-%20Abundance%20of%20Wintering%20Waterbirds.pdf
[80] https://www.npms.org.uk/
[81] http://www.ukbms.org/ and https://butterfly-conservation.org/our-work/recording-and-monitoring/wider-countryside-butterfly-survey
[82] https://butterfly-conservation.org/our-work/recording-and-monitoring/national-moth-recording-scheme
[83] https://www.nature.scot/scotlands-indicators-habitats-and-species-general-indicators
[84] https://nbn.org.uk/
[85] https://scotland.nbnatlas.org/
[86] https://www.nature.scot/sites/default/files/A1075307%20-%20Trend%20note%20-%20biodiversity%20-%20Farmland%20Birds%20in%20Scotland%20-%202013.pdf
[87] https://www.environment.gov.scot/our-environment/state-of-the-environment/ecosystem-health-indicators/explore-ecosystem-health-indicators/
[88] http://ukbap-reporting.org.uk/

Policy document	Aims/Targets	Policy output indicators	Delivering organisation and deadlines
Muirburn Code (2017)[89], page 6; guidance pertaining to the Hill Farming Act 1946, Wildlife & Countryside Act 1981 (as amended), and Nature Conservation (Scotland) Act 2004	Burning should not take place on peatland, except as part of a habitat restoration plan, approved by SNH (also see Section 7.1, and Supplementary Information 7 in Code). Areas with peat hags, bare peat or erosion should not be burnt.	None identified	SNH, 2020

[89] https://www.nature.scot/sites/default/files/2017-11/Guidance%20-%20Management%20of%20Moorland%20-%20Muirburn%20Code.pdf

Scottish Planning Policy (2014)[90], page 6-7; pertaining to National Planning Framework 3[91] UPDATE Themost recent version is the current draft National Planning Framework 4[92]	Outcome 2: A low carbon place – reducing our carbon emissions and adapting to climate change. A low carbon place Recognising the need for significant protection, in these areas (Group 2: Areas of significant protection) wind farms may be appropriate in some circumstances. Further consideration will be required to demonstrate that any significant effects on the qualities of these areas can be substantially overcome by siting, design or other mitigation (page 39). Outcome 3: A natural, resilient place – helping to protect and enhance our natural and cultural assets, and facilitating their sustainable use. A natural, resilient place (page 45) The planning system should: • facilitate positive change while maintaining and enhancing distinctive landscape character; • conserve and enhance protected sites and species, taking account of the need to maintain healthy ecosystems and work with the natural processes which provide important services to communities; • promote protection and improvement of the water environment, including rivers, lochs, estuaries, wetlands, coastal waters and groundwater, in a sustainable and co-ordinated way; • seek to protect soils from damage such as erosion or compaction; • seek benefits for biodiversity from new development where possible, including the restoration of degraded habitats and the avoidance of further fragmentation or isolation of habitats Where peat and other carbon rich soils are present, applicants should assess the likely effects of development on carbon dioxide (CO_2) emissions. Where peatland is drained or otherwise disturbed, there is liable to be a release of CO_2 to the atmosphere. Developments should aim to minimise this release (page 47). Promoting Responsible Extraction of Resources Policies should protect areas of peatland and only permit commercial extraction in areas suffering historic, significant damage through human activity and where the conservation value is low, and restoration is impossible (page 54)	None identified	Development Planning; Planning authorities, and all public bodies, ongoing

Policy document	Aims/Targets	Policy output indicators	Delivering organisation and deadlines
National Peatland Plan (2015), page 4	By 2020 we expect to see improvements in the protection and condition of peatlands. They will be valued by government policies, developers, land managers and the wider public and no longer seen just as special interest habitats. The public will embrace peat-free composts. Public funding remains the main source of support for peatland management and restoration, but the level of private funding is increasing. We will have in place a network of demonstration sites for good management, a Peatland Code supporting private funding of peatland conservation and restoration, and peatland management included in national carbon accounting. All of our statutory protected areas should be in, or moving towards, **favourable condition** – an exemplar of good management in rural Europe. The Flow Country will have moved from the Tentative List towards being a fully "inscribed" World Heritage Site.	Some of the outcomes of restoration are relatively easy to measure; raised water table, Sphagnum cover, absence of tree cover (unless bog woodland is target) etc. However, there are no 'off-the-shelf' protocols for these, let alone for more complex issues such as the greenhouse gas balance, economics and the water environment. Agreed protocols are needed to enable the cost-effectiveness of management and restoration to be measured. A few intensively monitored demonstration sites might assist with this. As peatland systems often require long term monitoring to provide useful information, equally long-term funding is required to support this.	Not specified; 2020
National Peatland Plan (2015), page 5	By 2030 we want to see peatlands in a **healthy** state and widely regarded as **resilient**. By now there will be global recognition of the multiple benefits of peatlands to society, reflected in the level of support directed at ensuring their management as healthy ecosystems. Funding for stewardship will have extended from public to private sources, with appropriate rewards for the benefits derived from the peatlands' natural capital and the services flowing from their healthy ecosystem functions. By now, peatlands are viewed as essential to the nation's wellbeing and natural capital.		Not specified; 2030.
National Peatland Plan (2015), page 5	2050 and beyond the rewards of restoration effort undertaken in previous decades should now be evident. The effects of a changing climate will be more apparent, but our peatlands are coping where restoration and sound management have increased their resilience. Restoration work continues and management to secure and maintain multiple benefits is the norm, with the income from this helping to maintain rural skills and employment.		Not specified; 2050 and beyond

[90] https://www2.gov.scot/Resource/0045/00453827.pdf
[91] https://www.gov.scot/publications/national-planning-framework-3/
[92] https://www.gov.scot/publications/national-planning-framework-4-revised-draft/

13. Appendix 2: Definitions of 'health', 'condition' and 'restored' in relation to peatlands

The most commonly used definitions of health in relation to ecosystems are those cited in the Millennium Assessment[93]: "An ecological system is healthy, if it is stable and sustainable—that is, if it is active and maintains its organization and autonomy over time and is resilient to stress" (Costanza et al. 1992:9; International Society for Ecosystem Health (ISEH)). In other words, *a useful definition is therefore that soil health is how well the soil does what you want it to do*. (Natural England[94], 2015). This considers whether the ecosystem and its external inputs are sustainable in the long term as well as whether the ecosystem can withstand or recover from disturbance (resistance and resilience, respectively) and similar issues".

The agreed working definition of "ecosystem health" published in the 2020 Challenge was: "The status of an ecosystem including the condition of its natural assets biodiversity/ geomorphology, its functional quality and its capacity to sustain both assets and function into the future (i.e. sustainability). The three interlinked elements are defined as follows:

• Condition of components (assets) – "how far they are from a 'good' state";

• Function – "the extent to which ecosystems retain their natural function and therefore have the capacity to deliver a range of benefits";

• Sustainability and resilience – "the extent to which ecosystems are resilient and their capacity to deliver benefits can be sustained under human and environmental pressures, including climate change."

The critical difference between these definitions comes in the word 'natural'. The Millennium Ecosystem definition can apply to a converted former blanket bog, as long as it fulfils the rest of the criteria, whereas the 2020 Challenge definition specifies a requirement for retaining their natural functions. For converted peatlands, few of the former natural functions are unaffected.

Embedded within the definition of health is 'condition', which in itself can have different definitions. The United Nations System of Environmental Economic Accounting uses the following: "Ecosystem condition reflects the overall quality of an ecosystem asset, in terms of its characteristics", with the term "characteristics" used to specify ecosystem components such as vegetation, biodiversity, soil, water and carbon in relation to both their quality and biophysical state measures[95].

Definitions of 'restored' vary, but generally are taken to mean to return something to, or put it back into, an earlier good condition, or state. The Peatland Action functional indicator of

[93] https://www.millenniumassessment.org/en/Framework.html

[94] http://publications.naturalengland.org.uk/publication/6432069183864832?category=6147530683318272

[95] http://doc.teebweb.org/wp-content/uploads/2017/01/ANCA-Tech-Guid-3.pdf

"on the road to recovery" is defined as "in the process of becoming healthy again". Achieving 'restored' status is therefore likely to be more difficult to prove than a status of 'on the road to recovery', however both definitions suggest that demonstration of a trajectory towards full ecosystem health as defined above, is required. Finally, the definition of ecological resilience is "the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks" (Holling, 1973; Walker et al, 2004) [96],[97]. The following table contains the basic ecosystem services that peatlands provide (Box 3) and was used as the basis for this report. Climate regulation is a specific ecosystem service within the Regulating services group. It can contain a number of subclasses of regulation, at global to local scale.

[96] https://www.ecologyandsociety.org/vol9/iss2/art5/
[97] https://www.annualreviews.org/doi/10.1146/annurev.es.04.110173.000245

Box 3. Ecosystem services of peatlands: Implications for restoration. From Kimmel and Mander (2010)[98].

Table 1. Peatland ecosystem services and relevant beneficial functions adapted from the Millennium Ecosystem Assessment (2005) and Joosten and Clarke (2002)

Ecosystem services of inland wetlands (Millennium Ecosystem Assessment, 2005)	Beneficial functions of peatlands (Joosten and Clarke, 2002)	Explanation/examples
Provisioning services	**Production functions**	
Fibre and fuel	Peat extracted and used/wild plants (including forests and energy biomass)	Peat used in horticulture, agriculture, domestic heating and energy generation/ raw material for industry and energy generation; medicine
Food	Wild plants/wild and domestic animals	Used as food for people and domestic animals/wood, fur and medicine
Fresh water	Water	Public water supply is obtained from reservoirs draining peatlands
	Peat substrate	Peatland space used for agriculture, horticulture and forestry
	Carrier functions	Space in peatlands for water reservoirs, infrastructure, waste deposits, landfills and military exercises and defence
Regulating services	**Regulation functions**	
Climate regulation	Regulation of global climate/ regional and local climates	Regulation of greenhouse gases, regulation of climatic processes
Water regulation	Regulation of catchment hydrology	Water storage, groundwater recharge and discharge
Water purification and waste treatment	Regulation of catchment hydrochemistry	Retention, recovery and removal of excess nutrients and pollutants
Erosion protection	Regulation of soil conditions	Peat blanket protecting the underlying soils from erosion
Cultural services	**Informational functions**	
Recreational and aesthetic	Recreation and aesthetic functions	Opportunities for recreation and tourism; appreciation of nature
Spiritual and inspirational	Spiritual and existential functions	Personal feelings and well-being; religious significance
Educational	Signalization and cognition functions	Opportunities for education, training and research
Supporting services		
Biodiversity		Habitats for species
Soil formation		Accumulation of organic matter
Nutrient cycling		Storage, recycling, processing and acquisition of nutrients

14. Appendix 3: Key uncertainties with IPCC Wetland Supplement Implementation

The primary uncertainties relating to the implementation of the 2013 IPCC Wetland Supplement are in relation to the areal extent of peatlands under the proposed land cover categories (termed the 'activity data' in the Inventory), and the associated emissions of

[98] https://journals.sagepub.com/doi/10.1177/0309133310365595

carbon dioxide, methane, nitrous oxide (and such gases as end products of the conversion of particulate and dissolved organic carbon in water courses), termed the ‘emission factors’. The former is primarily a ‘mapping problem’, but one that is currently not addressed in full (as per section 2.1, there are several gaps in evidence). As the UK GHG Inventory reporting cycle is annual, this will require significant effort as all the major land cover classes (cropland, woodland, semi-natural land, extraction, grassland, rewetted land) and likely subcategories within these classes that have different emissions, will need to be reported on annually. Updating the area of rewetted land, in particular (i.e. the area of land of the road to recovery), will be critical in terms of accounting for achieved GHG mitigation.

The second, the calculation of appropriate emissions, uses ‘emission factors’, that are based on either default values (Tier 1) as specified in the WS, country-specific emissions factors (Tier 2) or model-based (Tier 3) approaches. Countries with significant peatland area are encouraged to develop at least Tier 2 methodology, and it is here that that significant evidence gaps were identified by the WS Implementation project team (Evans et al, unpublished). The lack of country-specific data on peatland emissions was already identified in a JNCC-funded project in 2011, which, in two linked publications identified a potential design of a UK-wide measurement programme with several levels of implementation for peatlands in specific condition categories, based on their primary land cover and/or historic land use change type (e.g. afforestation, cropping, grazing, extracted, (semi-)natural and/or burning, drainage, restoration[99],[100] . UPDATE: Since completion of this report, implementation of the Evans et al (then unpublished) work into the UK Greenhouse Gas Inventory, LULUCF estimates, has been completed and revised emission factors are currently being implemented for the 1990-2022 revision[101].

[99] http://jncc.defra.gov.uk/pdf/jncc443_web.pdf
[100] http://jncc.defra.gov.uk/pdf/jncc442_webFinal.pd
[101] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1132550/ghg-national-statistics-methodology-changes1990-2021.pdf

15. Appendix 4: Key uncertainties with biodiversity monitoring

At present, indicators concerning peatland biodiversity obligations are generated using extrapolation or modelling of condition observed on areas on designated land (see Appendix 5).

The number of such protected species occurring specifically on peatlands is relatively small and overlap with related habitats (e.g. wet heathland) is common, complicating monitoring efforts for protected species. Similarly, statutory obligations under the EU Birds Directive can include peatlands, but data are not presently extracted under a common peatland monitoring framework. It is unclear whether a peatland monitoring framework should include status and trends of species, as this may depend on the definition of 'health' as per previous section. It can be argued that species diversity and abundance is part of the 'organisation' and critical 'components' of a peatland ecosystem, regardless of current land use.

Reporting currently includes sites with designation status under the Ramsar convention and the EU Habitats and Birds Directives. The Ramsar Convention covers wetlands of international importance. The UK hosts 74 sites on areas containing peat soils. All UK Ramsar reporting is currently overdue, meaning that data used are several years out of date at best. Similarly, under the EU Habitats Directive, Article 17[102], the UK and Devolved Administrations require to report on the condition of its eight UK peatland habitats on a rolling 6-year cycle. The eight UK peatland Annex I habitat types are Active raised mires; Degraded (but regenerating) raised mires; Blanket bog (active); Transition mires and quaking bogs; Peaty depressions –Rhynchosporion; Calcareous fens w. *Cladium*; Alkaline fens; Petrifying springs with tufa; and Alpine formations of *Caricion bicoloris*. Together, as stated previously, however, the area of designated peatland sites in Scotland is only 15% of the total peatland area and so the statistics pertaining to condition are likely biased towards sites that were in good enough condition to be protected in the first place. In addition, the long reporting cycles mean that resilience can only be assessed over the timescale of several decades, and thus is not really fit for purpose under the requirements of 3-yearly reporting in relation to the targets set in Table 1. This reliance on systematically biased data and lack of a systematic peatland monitoring framework in the UK was also highlighted in talks at the recent IUCN UK Peatland Committee conference.

There are also requirements to report on status and trends of specific Annex II, IV and V species and protection measures must be taken in accordance with their ecological requirements (Annex II and IV species) or measures taken to ensure any exploitation or wild harvesting is compatible with maintaining favourable conservation status.[103]

[102] http://ec.europa.eu/environment/nature/conservation/species/habitats_dir_en.htm.

16. Appendix 5: Potential monitoring methods

The following section provides short summaries of the current state of development of potential peatland condition indicators. *Please refer to Table 1 for the ecosystem services these indicators relate to.*

- A.5.1 Site-based Water table depth monitoring
- A.5.2. Direct on-site soil moisture monitoring
- A.5.3. Mapping peatland surface texture, moisture and surface motion using Synthetic Aperture Radar (SAR)
- A.5.4. Measurements of GHG exchange using eddy covariance or chambers
- A.5.5. Losses of carbon (e.g. DOC/POC) in water courses
- A.5.6. Earth Observations for monitoring of vegetation proxies, surface elevation or direct modelling of GHG emissions at different levels of resolution
    - A.5.6.a. Vegetation and condition classification (including indirect quantification of gross primary productivity) using Moderate Resolution Imaging Spectroradiometer (MODIS) data
    - A.5.6.b. high spatial resolution (Sentinel-2, Landsat, SPOT),
    - A.5.6.c. very high spatial resolution (UAV data/aerial photography)
    - A.5.6.d. LIDAR surface elevation mapping (drains/erosion)
    - A.5.6.e. Direct losses of particulate carbon (erosion)
- A.5.7. Proxy measure of carbon accumulation: e.g. Sphagnum height increment via cranked wires, direct fixed peat probes for C accumulation
- A.5.8. Common Standards Monitoring and analogues with primarily a vegetation focus (e.g. Habitat Condition Monitoring schemes)
- A.5.9. Other biodiversity monitoring

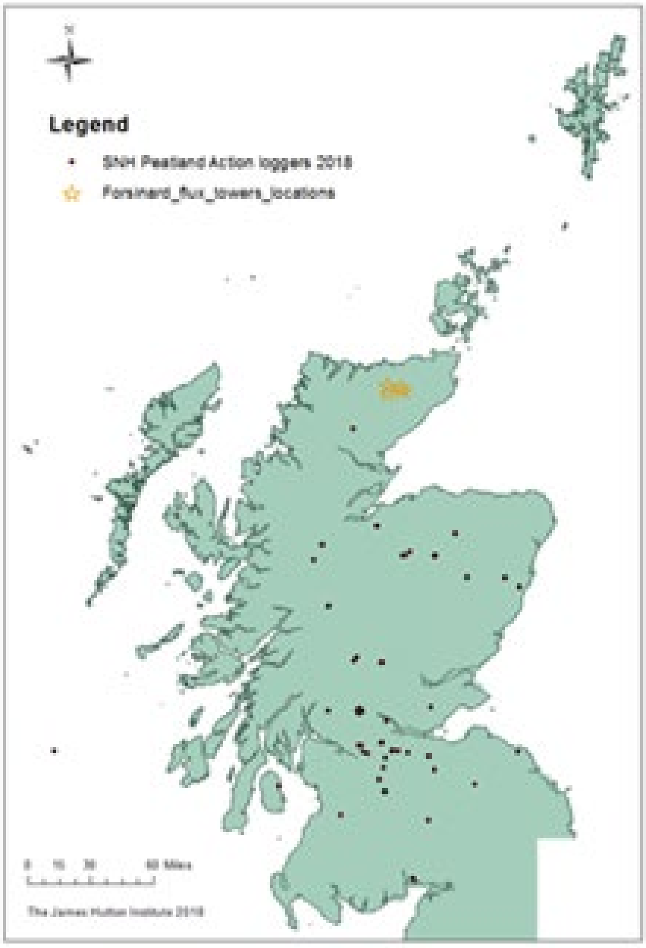
A.5.1. Method: Site-based water table depth monitoring

What can be monitored: Depending on spatial and temporal resolution of the monitoring, changes in water table dynamics can be assessed.

Pros: Automatic data loggers can provide sub-hourly data which can be assessed against precipitation data and resulting drying/rewetting curves can be useful indicators of recovery. At high spatial resolution, such information can be used to assess whether rewetting is uniform across a site or whether legacy issues persist in certain topographical features of a site. Manual monitoring of dipwells may be used to generate average water table depths across a site and can be a useful indictor of overall success

Cons: Longer-term monitoring (>5 years) is generally required to ascertain responses to more extreme conditions. Manual monitoring often lacks the data resolution to assess drying/rewetting phases and is therefore of less value if intended to inform future performance with modelling efforts.

Current state of development: It is currently unknown how many water table depth monitoring projects are operating across Scotland's peatlands. The best example of compiled data at present are from SNH Peatland Action, who are in the process of compiling their database of projects with hydrological monitoring. These sites comprise a reasonably spatially dispersed dataset (Figure, left), however it is unknown whether the data acquisition at these sites is comparable, and whether these efforts are sufficient to enable potential linkages to modelling efforts. UPDATE: There are now a larger number of monitoring sites across Scotland.



What's required for upscaling: It is unknown whether the data acquisition is sufficient to enable potential linkages to modelling efforts.

A.5.2. Method: Direct on-site soil moisture monitoring

What can be monitored: Changes in soil surface moisture can be assessed indirectly by using some other property of the soil, such as electrical resistance, dielectric constant, or interaction with neutrons, as a proxy for the moisture content. Electric resistance and dielectric constant-based monitors can includer hand-held instruments as well as data loggers. Primary cosmic-rays are high-energy sub-atomic particles from outer space that are 90% protons. When these particles collide with atoms in the air on entry into the atmosphere, a shower of secondary particles are generated, including fast neutrons. Neutrons collide with hydrogen nucleii in the soil and are then converted to thermalised (slow) neutrons that are reflected. These can then be detected by a sensor. The COSMOS network uses such cosmic ray soil moisture sensors at a number of sites across the UK. The sensors integrate soil moisture over large areas (up to 400 m in diameter) and up to a variable depth (as little as 15 cm in wet soils).

Pros: Automatic soil moisture loggers can provide sub-hourly data which can be assessed against precipitation data and resulting drying/rewetting curves can be useful indicators of recovery. At high spatial resolution, such information can be used to assess whether rewetting is uniform across a site or whether legacy issues persist in certain topographical features of a site. COSMOS stations measure over a large area, providing an integrative measurement and such data could be useful to build models for remote assessments (e.g. A5.3)

Cons: UK conditions, i.e. relatively high soil wetness, low altitude and high soil organic carbon (peat) at particular sites, reduce the number of neutron counts. This can lead to processed values of >100% volumetric water content and therefore the method cannot always be considered reliable on peat soils. Longer-term monitoring (>5 years) is generally required to ascertain responses to more extreme conditions. Electric resistance and dielectric constant-based monitors are often not developed for use in peat soils and can tend to return saturated volumetric moisture content even when this is not the case

Current state of development: It is currently unknown how many soil moisture monitoring projects are operating across Scotland's peatlands. UPDATE: A small network of sites are now being monitored via the RESAS Scottish Strategic Research Programme 2022-2027.

What's required for upscaling: It is unknown whether the data acquisition is sufficient to enable potential linkages to modelling efforts.

A.5.3. Method: Mapping peatland surface texture, moisture and surface motion using Synthetic Aperture Radar (SAR)

What can be monitored: Synthetic Aperture Radar (SAR) utilises the motion of a moving radar over a target to simulate a large (synthetic) radar antennae, facilitating the acquisition of high resolution 2D and 3D images – e.g. landscapes. The further the antennae travels the larger the synthetic aperture which, in turn, enables the creation of finer detailed images. SAR antennae are, therefore, typically mounted on aircraft and satellites. The resolution of imagery ranges from centimetres / millimetres (e.g. Sentinel 1) to sub-millimetre (laboratory). SAR has been widely used on both aerial and space-based platforms for earth observation including ERS-1/2, JERS-1, Envisat ASAR, RADARSAT-1, ALOS PALSAR, TerraSAR-X and COSMO-SkyMed, Space Shuttle missions SIR-A and SIR-B, the Shuttle Radar Topography Mission (SRTM) as well as ESA's Sentinel 1A/B satellites. Data can be analysed to interrogate surface texture, which can be an indicator of the land cover[104]. Texture data can be combined with optical data and may contribute additional classification power. Another application is surface moisture level modelling[105].

A third common technique used in landscape remote sensing is surface motion modelling using interferometric synthetic aperture radar (InSAR)[106]. Interferometry utilises two (or more) SAR images to generate digital elevation maps which can measure millimetric changes in the landscape.

Sentinel 1A/B employs C-band InSAR with four spatial resolutions:

Strip Map: 5x5 metre resolution with an 80 Km swath. Used for monitoring small islands and for emergency management. *Interferometric Wide Swath:* 5x20 metre resolution with a 250 km swath. This is the main mode used over land and wetlands. *Extra Wide Swath:* 25 x 100 metre resolution with a 400 Km swath. Used for monitoring wide coastal areas. *Wave Mode:* 5 x20 metre resolution producing 20 x 20 km images. This is the main mode used over open ocean.

Pros: SAR is not dependent on weather or daylight, thus enabling monitoring through cloud cover and at night. Radar interferometry allows monitoring of ground movement as small as a few millimetres and is therefore useful in monitoring seasonal (vertical) peat movement. SAR can detect the finer details of vegetation and can identify different types of wetland vegetation and surface roughness and can therefore differentiate between land and wetland. L-band SAR is very sensitive to surface water, benefiting to hydrology, ecology, meteorology, and could be used to monitor peatland pool sizes and flooding/drought. Data acquisition rates are high and data are freely available.

Cons: No consistent record of SAR imagery as SAR acquisition has largely been on request. UPDATE: The Sentinel-1 C-band acquisition data catalogue is now comprehensive enough for this to no longer apply.

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[104] https://ieeexplore.ieee.org/document/7762813
[105] https://www.mdpi.com/2072-4292/10/6/903; https://www.mdpi.com/2072-4292/10/4/536
[106] https://gtr.ukri.org/projects?ref=NE%2FP014100%2F1

Current state of development: Research only. UPDATE: Some major progress has been made in testing both backscatter SAR for peatland water table depth modelling and interferometric SAR for more general peatland condition modelling, e.g. [107], [108] and so these methods are developing rapidly into becoming potentially suitable to large scape monitoring tools.

What's required for upscaling: Ground observations for model training and testing. UPDATE: At the present time, enither backscatter not interferometric SAR-based models have been tested at national scale, although some good results have been obtained with local to regional pilots.

[107] https://www.nature.scot/satellites-track-bog-breathing-help-monitor-peatlands
[108] https://www.tandfonline.com/doi/full/10.1080/01431161.2022.2131478

A.5.4. Method: Measurements of greenhouse gas (GHG) exchange using eddy covariance or chambers

What can be monitored: There are two widely used methods for measuring the exchange of GHGs over vegetation that are applied to peatlands across the UK:

Eddy covariance (EC): The core instruments required to measure CO_2 flux by eddy-covariance are a sonic anemometer and infra-red gas analyser (IRGA). The sonic anemometer measures the 3-dimensional windspeeds at ~10 – 20 Hz while the IRGA measures CO_2 and H_2O concentration, also at ~20 Hz. From these measurements the upward or downward fluxes of energy (sensible heat, latent heat and momentum) and CO_2, can be calculated using the core relationship:

$F = b. \overline{(w'X')}$

Where: F = flux

w' = instantaneous value of vertical windspeed about the mean
X' = instantaneous value of tracer X amount it's mean
b = is a scaling factor to convert to specific units as required

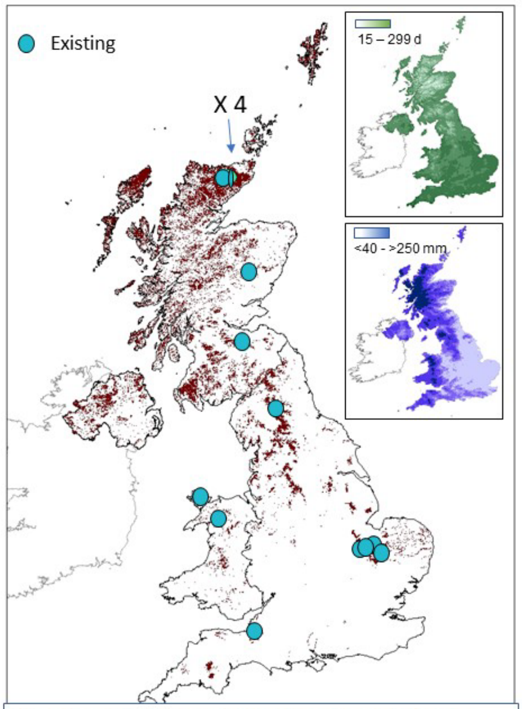
Other greenhouse gas fluxes such as for methane (CH_4) and nitrous oxide (N_2O) can also be measured if fast response instruments can be installed to run alongside the sonic and IRGA. Other environmental variables such as air temperature, relative humidity, incoming and outgoing solar radiation, soil temperature, soil moisture content, rainfall and air pressure, are measured alongside the EC instruments to assist in interpretation of the data.

Chamber systems: there are different types of chambers, but they all operate on the same principle of measuring the rate of change of gases within the chamber when it covers an area of vegetation or soil. In some applications the chamber is simply sealed, and samples of the internal air drawn off at regular intervals. These samples are then analysed in a laboratory with an instrument such as a GC, to measure the concentrations of the GHG at each time step. To improve the sampling the air in the chamber may be mixed with a battery powered fan and a small vent added to ensure the gas exchange is not affected by pressure changes. In dynamic systems the air from the chamber is pumped directed to an instrument that measures the concentration changes in real time. This has the advantage that more readings are taken over the period, but the instruments required to measure some greenhouse gases, such as N_2O can be expensive and cumbersome to use in the field. It is common to measure environmental variables such as soil temperature, soil moisture content and solar radiation, alongside the chambers to assist in interpretation of the data.

These two methods have certain advantages and disadvantages, summarised below:

Method	Pros	Cons
Eddy-covariance	- Realtime in situ measurements - Gives a measurement applicable over a wide area (around 100 m^2 to several km^2), averaging small inhomogeneities - Requires little user intervention once set up	- Requires very specific topographic conditions - Expensive equipment and specialist data processing/interpretation skills - Only CO_2 & CH_4 available on low-power (12 V DC solar panels etc) - Data analysis can be complex
Chambers	- Basic equipment is simple and affordable - Good for examining small scale processes controlling exchange - Time consuming - Hard to accurately scale-up to the field or landscape scale	Need to balance the number of chambers versus inhomogeneity to adequately capture exchange. Manual measurements tend to overestimate emissions as night-time fluxes are rarely sufficiently assessed or corrected for.

Current state of development: One of the complexities of understanding carbon exchange is the large amount of inter-year variability which necessitates measurements over several years, alongside other environmental variables, to give an accurate assessment of the carbon budget for an ecosystem. These long-running EC flux towers (Figure, left. The majority of these locations have only CO_2 monitoring capacity at present) have the potential to provide a wealth, if information on CO_2 exchange and the data are currently being collated and stored in a database system that will allow quick and consistent analysis across all the sites. For CH_4 and N_2O data are more limited but with the addition of low-power CH_4 instruments at some sites the amount of data available is increasing. For peatlands this is particularly relevant as the exchange of CH_4 and CO_2 can be anti-correlated and so having both greatly improves estimated of the total carbon budget. For Scotland, only a few annual GHG and, in one case, full site carbon, budgets (i.e. including aqueous) have been published (Levy and Gray,



Flux tower locations on peatland in relation to growing season (top inset) and precipitation gradients (bottom inset, 1981-2010 averages)

2015[109]; Dinsmore et al., 2010[110]). UPDATE: The current site network is larger than shown in this report, and was upgraded to have more sties with methane monitoring capacity. It is currently supported by the RESAS Strategic Research Programme 2022-2027[111].

What's required for upscaling: There are currently an insufficient number of observations on some classes of peatlands under converted land use, such as eroded peatlands and drained peatland. Longer term monitoring is required to establish interannual variation with a higher degree of certainty. NOTE: An additional 2-3 monitoring stations are likely to be added to the Scottish network in 2020. There are also calls for further monitoring stations in England, with a focus on wasted, agricultural, peatlands.

[109] http://nora.nerc.ac.uk/511853/1/N511853JA.pdf
[110] https://onlinelibrary.wiley.com/doi/10.1111/j.1365-2486.2009.02119.x
[111] https://zenodo.org/record/7386016#.Y-09YYTP3IU

A.5.5. Method: Carbon export from peatlands associated with dissolved organic carbon (DOC) and/or particulate organic carbon (POC) export to watercourses

What can be monitored: Dissolved and particulate organic carbon in stream water

Pros:

- The sampling and analytical techniques are well-established and used routinely in monitoring, research and casework.
- Monitoring is taking place in the UK and therefore there may be datasets for some sites from which C export could be calculated and used for upscaling.

Cons:

- Existing monitoring is patchy in time and space - may not cover peatland catchments. High quality datasets that have sufficient spatio-temporal resolution to allow for investigation of drivers and load calculations are very sparse (e.g. Environmental Change Network (ECN), a few of the EC flux sites; SEPA's extensive network is not able to supply such data). There are very few net ecosystem C budget studies for peatland soils appropriate to the UK.
- Some datasets may be subject to confidentiality agreements and therefore take time to procure.
- Sampling points may be lower down the catchments and not in headwaters. To relate these data to losses requires an understanding of rates of processing and storage in transit through the river system.
- Data from different sources are gathered using different techniques and expressed in different ways (concentrations, loads, yields etc). This is more of an issue for POC than DOC.
- There is a lack of knowledge as to the extent that reactive organic C, once destabilised from terrestrial stores, is returned as CO_2 to the atmosphere by biological processing within aquatic systems.

Current state of development:

Existing datasets:

- SW monitor DOC/POC, but the details of the studies are not known (data are not publicly available). It is likely that this is via colour absorbance – this is however a poor surrogate for DOC overall. POC data is near non-existent as it is difficult to determine POC directly; surrogate data are generally not of sufficient robustness.
- DOC assessment is now part of SEPA's surveillance (long term assessment network) and operational (targeted at status assessments in catchments at risk) monitoring – Both networks were reviewed in 2007. Data are held in SEPA's Characterisation Database.
- Also measured in an assessment of 56 rivers but sampled close to tidal limit and therefore use requires correlations to be calculated.
- James Hutton Institute may hold research data from the ECN (Stutter et al)
- There are casework studies relating to e.g. windfarm construction and deforestation (Waldron et al., Glasgow and Heal et al, Edinburgh Universities.

- Although a comprehensive review reviewed the UK data resource was undertaken in 2011, there may be new studies or datasets to include.
- There are very few net ecosystem C budget studies for peatland soils appropriate to the UK (perhaps only two, Auchencorth and Moor House and only the former was empirically measured, not modelled).
- We don't know how much organic C is returned to the atmosphere from freshwaters i.e. how much aquatic C is bioreactive. The fate of DOC in aquatic systems and controls on breakdown/cycling is topical but I don't know how advanced current knowledge is?
- UPDATE: James Hutton Institute currently monitors two sites for POC and DOC from unrestored/restored eroded microcatchments as part of the RESAS Scottish Research Programme 2022-2027.

What's required for upscaling:

What's unknown?	What's required?
The coverage and potential suitability of existing data (including the availability and utility of data held by stakeholders)	Input from stakeholders (SEPA, SW) on data availability (£) An update to the 2011 SNIFFER report, with a focus on the utility of datasets for calculations of aqueous C losses (analytical method, location of sampling on river network, coverage of peatland types, flow conditions, seasonality etc). (££)
If coverage sufficient	A desk/modelling exercise to estimate exports (££)
If coverage insufficient	A monitoring/research study (£££)
The fate of DOC in aquatic systems and controls on breakdown/cycling	Research programme: (£££) • To what extent are reactive organic C, once destabilised from terrestrial stores, returned as CO_2 to the atmosphere by biological processing within aquatic systems. • What are the relative roles of the different C components in aquatic transfers? • How important are aquatic losses in relation to changes in the terrestrial C stores?

A.5.6.a. Method: Vegetation and condition classification (including indirect quantification of gross primary productivity) using Moderate Resolution Imaging Spectroradiometer (MODIS) data

What can be monitored: The MODIS satellite has been in orbit since 1999. Its data products are 36 spectral bands at varying spatial resolutions (250 m, bands 1-2; 500 m, bands 3-7; 1000m, bands 8-36). MODIS data can be used to monitor relatively large-scale changes within the landscape over time. The sensor collects global data every 1-2 days, but many of the publicly available products are available as composite images or derived products that are compiled for daily-monthly periods. Both the composite datasets and derived products have been used to monitor vegetation condition by means of time-series analyses with vegetation indices, long term land-cover changes, land surface temperature and albedo changes, evapotranspiration, flooding and atmospheric conditions including smoke and thermal anomalies as produced by fires).

Pros: Long term data coverage allows for model development over long timescales. Data acquisition rates are very high. Data are publicly available since start of data capture, allowing lost cost monitoring over a decadal timespan.

Cons: The limitation for peatlands are primarily in the relatively low spatial resolution (generally 500 m or less, which may restrict application for small wetlands, and the derived products have not been designed with peatlands in mind (for example, the derived Gross Primary Productivity product did not use peatland vegetation as a classifying category, leading to large overestimation compared with site observations (Lees et al., 2019[112]). Multi-spectral images must be collected in daylight and can be limited by cloud cover, tree canopy cover and atmospheric conditions.

Current state of development: Requiring further validation. A national scale (500 m resolution) model of peatland condition (favourable/unfavourable) in Scotland has been produced for a median 2002-2011 period (Artz et al., 2019)[113], using training data from the Common Standards Monitoring programme and limited external validation using other data sources. Further development would be useful to produce an update for the current situation and to check whether it is feasible to produce annual updates.

What's required for upscaling: The feasibility of annual updates has not been tested (the current model has not been run predictively) and is dependent on sufficient ground observations to validate the model. We estimate there would be a relatively moderate costs to test this (mostly staff time, possibly collation of suitable ground observations).

[112] https://www.sciencedirect.com/science/article/pii/S0301479719303421?via%3Dihub
[113] https://www.sciencedirect.com/science/article/pii/S0048969718352124

A.5.6.b Method: Mapping peatland condition using remote sensing – 2. High spatial resolution (Landsat; originally named Earth Resources Technology Satellite).

What can be monitored: Landsat is the longest running satellite-based earth-imagery acquisition program. The first Landsat was launched in 1972. **Landsat 7** (still active) was launched in 1999. It collects global data for each point on earth every 16 days. Its data sensors include an Enhanced Thematic Mapper Plus (ETM+). It has 8 spectral bands at varying spatial resolutions (30m, bands 1/2/3/4/5/6/7; 15m, band 8). The scan line corrector failed in May 2003 and was switched off, resulting in a 25% loss of data for any scene. **Landsat 8** (still active) was launched in 2013. It collects global data for each point on earth every 16 days in an 8-day offset with Landsat 7. Its data sensors include the Operational Land Imager (OLI) and the Thermal InfraRed Sensor (TIRS). It has 11 spectral bands at varying spatial resolutions (30m, bands 1/2/3/4/5/6/7/9/10/11; 15m, band 8). Landsat 9 is expected to be launched in 2020. Landsat imagery is used for widely used for long-term land-cover, agriculture, cartography, climate change, geology, forestry, regional planning, surveillance and education.

Pros: Long-term data coverage allows for modelling changes in peatlands over extended timescales. Data acquisition rates are moderate. Imagery covers large areas – approx. 185 km long x 185 km wide and is low-cost or freely available. Landsat imagery can distinguish between peatland and non-peatland and can detect small changes in the landscape.

Cons: Although the resolution of the Landsat sensors is higher than that of MODIS (30m as opposed to 250-500m) it is still insufficient to identify different peatland vegetation types. As with any multi-spectral platform images must be collected in daylight and can be limited by cloud cover, tree canopy cover and atmospheric conditions.

Current state of development: Requiring further validation. Currently only used in a research context, and only some relatively small-scale peatland condition assessments have been published to date for Scotland (Brown, Aitkenhead, Wright and Aalders, 2007[114]). In Scotland there is one ongoing academic collaboration between Peatland ACTION and the University of Nottingham (the 'Bog Breathing' project).

What's required for upscaling: Not yet been tested at national scale to estimate condition and would require substantially more computing capacity than previous work using MODIS (see previous section A.5.6.a).

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[114] https://www.tandfonline.com/doi/abs/10.1080/14702540701786912

A.5.6.c. Method: Mapping peatland condition using remote sensing – 3. High spatial resolution (Sentinel -2.; Coordinated and managed under the European Commission's Copernicus programme, the European Space Agency, EU member states and agencies.[115]

What can be monitored:

Sentinel 2A, launched 2015, and Sentinel 2B, launched 2017, provide high-resolution multi-spectral data in 13 bands (10m, bands 2/3/4/8; 20m, bands 5,6,7,8A,11,12; 60m, bands 1,9,10). They collect global data for each point between 56° S to 84° N every 5 days. Sentinel 2 imagery is used for monitoring and managing agriculture, forestry, food security, humanitarian relief, glacier and snow cover, flooding, marine and coastal environments; measuring various plant indices such as chlorophyll and water content, mapping changes in land cover, mapping and monitoring pollution in lakes and oceans.

Pros: Imagery collected by Sentinel 2 A and B covers a wide 290 km swath at a resolution higher than that of Landsat and MODIS (10/20/60m as opposed to 20/30m and 250/500m respectively). Data acquisition rates are high, and data are freely available.

Cons: Sentinel 2: As with any multi-spectral platform images must be collected in daylight and can be limited by cloud cover, tree canopy cover and atmospheric conditions. Resolution for peatland monitoring?

Current state of development: A peatland classification pilot study across 4 test areas in the UK (100 km^2 each) was carried out under a Defra/JNCC project but the work is currently still unpublished. There is an ongoing project to test a model of peatland restoration timelines, including effectiveness to achieve target condition, using Sentinel-2 data within the current RESAS Strategic Research Programme (James Hutton Institute). The possibility of adding Anthropogenic CO_2 emissions monitoring (CO2M) to a future Sentinel satellite is currently being studied.

What's required for upscaling: Not yet been tested at national scale to estimate condition and would require substantially more computing capacity than previous work using MODIS (see previous section A.5.6.a).

[115] There is another set of satellites, Sentinel 3A, launched 2016, and Sentinel 3B, launched 2018, that provide high-resolution multi-spectral data in 21 bands in a swath of 1270 Km at a 300m resolution. The also carry Sea and Land Surface Temperature Radiometers (500m - 1Km spatial resolution), Synthetic aperture Radar Altimeters (300m resolution) and a microwave radiometer. However, Sentinel 3 is primarily intended for ocean monitoring.

A5.6.d. Method: Mapping peatland condition using remote sensing – 4. very high spatial resolution (UAV data/aerial photography)

What can be monitored: Aerial photography is widely used in cartography, land-use planning and environmental studies.

Aerial photography includes photography taken from fixed-wing aircraft, helicopters, unmanned aerial vehicles (UAVs), balloons, blimps and dirigibles, rockets, kites, stand-alone telescoping and vehicle-mounted poles. Up until the 1940s most aerial photography was oblique. However, the generation of orthophotos, which can be used in Geographical Information Systems (GIS) as maps, requires that the photography be taken vertically, and most survey-based aerial photography has since been vertical. Orthophotos are referenced (for parallax and changing ground elevations) against real-world coordinates and can therefore provide information such as distance, bearing and size (area), and can be seamlessly tiled with adjacent photographs. Examples of this can be found in Google Earth, Google Maps and OpenStreetMap, and can be purchased from Ordinance Survey, Get Mapping and Blue Sky.

Up until the 2000s commercially available (e.g. Ordnance Survey) colour aerial photography was restricted to urban areas with monochrome photography being used for rural areas. The resolution of early (1950s) aerial photographs was approx. 0.5 metres with a coverage of approx. 25 square kilometres. Colour photography now covers the whole of the UK and can be purchased from survey companies at a resolution of 0.25 metres. Because of their proximity to ground aerial photography by UAVs can have resolutions as high as 0.05 metres. Aerial photography is not limited to imaging in the visible light spectrum. Infra-red photography is often taken simultaneously and has been used since the 1960s to identify vegetation types and water bodies.

Pros: As the aerial survey operator has control over when the aircraft is flown aerial images tend to be more cloud free than those taken by satellite. The shorter vertical distance from the camera to the ground (compares to satellite imagery) helps reduce haze. Aerial photography also tends to be cheaper than satellite imagery of equivalent resolution. The resolution of aerial imagery can be sufficient to identify vegetation types.

Cons: The operation of fixed wing aircraft is expensive and therefore prohibits re-photographing of the same area at short time scales. In the 20th century, rural areas were often photographed only at 10-20 year intervals. This can be a problem in highly dynamic environments. The development of cheap UAVs with fairly simple operational requirements will probably address this but producing national coverage (at frequent intervals) is unlikely to be cost effective from UAV data. The limited and variable spectral resolution of aerial photography can introduce further limitations.

Current state of development: Developments in low-cost high-resolution digital imaging, together with UAV technology, has made it possible to undertake aerial photography/imaging at a much lower cost with more frequent revisits to sites.

What's required for upscaling: Not likely to be suitable beyond local assessments due to data storage/computing requirements.

A.5.6.e. Method: surface elevation mapping using Light Imaging, Detection and Ranging (LIDAR)

What can be monitored: LIDAR uses pulsed laser light to measure distances from source to the target and is employed for the generation of high-resolution 3D imagery in geodesy, geomatics, archaeology, geography, geology, geomorphology, seismology and forestry. LIDAR can be operated on airborne, terrestrial and mobile platforms, though airborne systems (fixed wing and Unmanned Aerial Vehicles (UAVs)) are the most commonly platform used in landscape mapping. Lidar can map landscapes at a very high resolution, ranging from 25 cm (fixed wing aircraft) to approx. 6 cm (UAVs). Wavelengths may vary from 1064 nm (used for aerial topographic surveys) to 532 nm (used for bathymetric surveys). Care must be taken to ensure that the laser used is either eye-safe and / or that safety precautions are in place. Outputs are usually a 3-D point cloud which can be used to create a digital surface model (DSM) or may be further processed to remove any reflections from trees and vegetation in order to create a digital terrain model (DTM).

Pros; LIDAR is more accurate and capable of showing more detail in landscapes than conventional photogrammetry. The strong absorption of laser energy by water makes LIDAR well suited for sensing areas of inundation. Differing LIDAR returns can distinguish between the earth's surface and tree/vegetation canopy, considerably improving its ability to detect areas of inundation. High resolution LIDAR, in conjunction with machine learning, can identify different plant species.

Cons: Certain wavelengths, particularly Near Infra-Red (NIR) may be totally absorbed by water, causing inundated areas to show as 'no data', which can be a problem when mapping tidal wetlands.

Current state of development: LIDAR is widely used in forestry and biodiversity studies and has been utilised in conjunction with 2D imagery in a process called 'Object-Based Image Analysis' (OBIA) to classify wetland classes and aquatic vegetation with a high degree of accuracy, however it has not been applied in a Scottish context.

What's required for upscaling: Data coverage of publicly available LiDAR across Scotland is still too low to consider upscaling.

A.5.7. Method: Direct losses of carbon through oxidation and/or losses of particulate carbon (erosion)

What can be monitored:

Generically, standard soil monitoring programmes generally use traditional soil survey methods, i.e. soil profile (pits) assessments of individual soil horizons thickness and sampling for e.g., bulk density and soil carbon content. Such traditional techniques have value in peatlands in providing a long-term (multi-decadal) framework for assessing broadscale changes and so should not be discounted even when assessing condition on time scales considered in this paper (annual and/or sub-decadal reporting).

Measurements of peatland erosion have traditionally been carried out using erosion pins[116], often combined with sediment traps[117]. Such measurements have generally estimated erosion rates of <1 to 4 cm of peat loss per year in areas where erosion is an issue. However, some of these losses may not leave the catchment but settle elsewhere. For example, passive horizontal mass flux gauges have been used to monitor such wind-borne erosion combined with sediment traps and found significantly higher peat in windward facing traps[118]. Few of these methods are upscalable, hence modern methods of monitoring erosion utilise laser-based techniques, which build a 3-D surface elevation model from either ground[119] or airborne LiDAR measurements, or satellite-based surface motion estimates (see A.5.3).

Pros: Traditional soil survey methods allow continuity with existing schemes, e.g. the National Soil Inventory for Scotland, which has been in existence for 40 years and allows assessment of all Scotland's soils using the same methodology.

Erosion pins and sediment traps are low cost options but require regular visits by staff to take measurements and ensure stability of the equipment. LiDAR and satellite-based measures can cover larger areas in principle.

Cons: Traditional soil survey methods will not be sensitive enough to pick up the small changes that would be taking place on annual or subdecadal timescales in peatlands. Standard rrosion monitoring is still very challenging, as there can be periods of active erosion followed by resettlement, particularly after a drought. Erosion pins and sediment traps need to be stable to produce accurate results, but are often prone to movement due to freeze-thaw cycles and/or natural peat surface oscillation due to peat shrinkage or expansion ('bog breathing') due to natural production of gases in the peat column and the effects of drying and rewetting on an annual cycle. These manual measurements also can't provide data beyond spot measurements – the cost of monitoring across large areas becomes prohibitive due to the requirement to visit the locations. LiDAR or satellite-based

116 https://www.tandfonline.com/doi/abs/10.1080/00369229318736871
117 https://onlinelibrary.wiley.com/doi/epdf/10.1002/esp.3290150507
118 https://www.sciencedirect.com/science/article/abs/pii/S0341816203000146
119 http://eprints.whiterose.ac.uk/77442/14/Lidar%20erosion%20paper%20WR_with_coversheet.pdf

monitoring is not yet available off-the-shelf, due to the cost of LiDAR and the only relatively recently available time series of high-resolution satellite data.

Current state of development: Research only.

What's required for upscaling: No monitoring network in place UPDATE: Two sites in Aberdeenshire are now being monitored as part of the RESAS Strategic Research Programme.

A.5.8. Method: Proxy measure of carbon accumulation: e.g. Sphagnum height increment via cranked wires, direct fixed peat probes for C accumulation

What can be monitored: Measuring the growth rate (primary productivity) of Sphagnum mosses can be a quick and simple indicator of carbon accumulation. A manual method for this is provided via the modified cracked wire technique[120], [121]. This uses wires permanently anchored into growing Sphagnum and growth increment is measured between the top of the Sphagnum capitulum and the top of the 'crank' in the wire. It is not a direct method of estimating carbon accumulation. A more direct method is installation of fixed probes into the peat that are anchored into the material (mineral soil or bedrock) below the peat mass. Annual changes in peat height can then be monitored and, over the long term, an estimate of peat increment or subsidence be established [122]. Another method is to measure the peat depth using ground penetrating radar.

Pros: Both the first two methods are very inexpensive to put into place but require regular visits on the ground. While GPR equipment can be more expensive to hire, this is a non-invasive technique that can cover larger areas.

Cons: The Sphagnum growth method is only a rough proxy of accumulation as it doesn't take into account potential losses through ecosystem respiration. Fixed peat probe monitoring requires several years' worth of data before an accurate result can be obtained as 'peat breathing' may obscure the long-term trend. There is a way to correct for bog breathing using monitoring of the position of a metal plate buried next to the fixed-point peat probe, the plate will move in relation to the level of vertical movement of the peat[123]. GPR requires trained operators and data handling skills. However, all methods are only suitable for point locations or small sites, monitoring across a larger area is challenging due to the requirement for manual data collection.

Current state of development: Research only

What's required for upscaling: No monitoring network in place. There is an experimental platform (Eyes on the Bog) via IUCN UK Peatland Programme for fixed point peat probes, but no information is available in the public domain on the number, location or data availability of such sites.

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120 http://research.sbcs.qmul.ac.uk/r.clymo/Clymo-article-PDFs/10-Clymo-1970-Sphagnum-measurement.pdf

121 https://core.ac.uk/download/pdf/84729015.pdf

122 https://www.iucn-uk-peatlandprogramme.org/sites/default/files/header-images/Eyes%20on%20the%20Bog%20Manual.pdf

123 https://www.iucn-uk-peatlandprogramme.org/sites/default/files/header-images/Conserving%20Bogs%20the%20management%20handbook.pdf

A.5.9. Method: Common Standards Monitoring and Habitat Impact Assessment

What can be monitored: Within Common Standards Monitoring (also known as Site Condition Monitoring) a range of attributes of each habitat (feature) is made. For example, for Blanket Bog[124] () this includes (1) extent, (2) frequency of indicator species, (3) cover of indicator species, (4) cover of non-natives, trees, grassland species, (5) indicators of browsing, (6) indicators of disturbance, (8) peat erosion and (9) drainage. Each indicator is scored against a set of targets and each feature is scored as to whether it is in favourable condition, favourable recovered, unfavourable recovering, unfavourable no change, unfavourable declining, partially destroyed, destroyed. Habitat Impact Assessment was developed to identify the main drivers of poor condition to allow for issues with management to be assessed and improvements monitored.

Pros: It is a key responsibility of statutory nature conservation organisations to monitor designated sites such as SSSIs and SACs. Consequently, this data has been recorded every six years to allow reporting against national and European targets.

Cons: The methods are semi-quantitative and consequently it is difficult to assess change given the categorisation of the data; a small change might tip over one feature into another category whilst a more substantial change may shift a feature within the range of a category. Also, there are inconsistencies in the way condition or impact are recorded between surveyors, so drawing conclusions from surveys carried out by different surveyors is difficult [125],[126](MacDonald 2010, Pakeman 2007).

Current state of development: These are well established methods and Common Standards Monitoring forms the basis for reporting to the European commission and is one of the indicators that contribute to the National Performance Framework. However, the current view is that monitoring and surveillance methods are to be revamped and it is uncertain whether future methods will be backward compatible. In recent years monitoring has become more focussed on risk and this trend is set to continue – this means that recent and future data will be less representative of the whole resource as data collection will focus most on sites currently or likely to experience impacts.

What is required for upscaling: As both methods are focussed at protected sites, then this data set has always been problematic in being used to represent national trends for the whole peatland resource. However, changes to a more risk focussed sampling of sites means that data will be further removed from being useful for monitoring the resource as a whole. Data could be useful to ground truth other methods of assessment, especially remote sensing methods.

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[124] http://jncc.defra.gov.uk/pdf/CSM_Upland_jul_09.pdf

[125] MacDonald, A.J. (2010) Testing the reliability of assessment of land management impacts on Scottish upland vegetation. *Plant Ecology & Diversity*, *3*, 301-312.

[126] Pakeman, R. (2008) Analysis of Habitat Impact Assessment Data from Recent Joint-Working Sites. Impacts on Blanket Bog Habitats. February 2007 to March 2008. Report to Scottish Natural Heritage

A.5.10. Method: Other biodiversity monitoring

Method: A wide range of biodiversity data is collected by professional and citizen scientists ranging from the strict sampling of breeding birds (https://www.bto.org/volunteer-surveys/bbs) to ad hoc recoding of species in data supplied to the National Biodiversity Network and local record centres.

What can be monitored: Data are available in some form for many species. However, the ad hoc data is not suitable for monitoring except over large spatial scales and long time frames, complex statistical methods must be employed to adjust for biases in the data[127]. Structured monitoring schemes, such as those for birds and butterflies, provide time-series data, but due to the small sample sizes, downscaling to a habitat would be problematic. Trends are available for Scotland from these schemes, but not at smaller spatial scales.

Pros: Free and, often, easily accessible data.

Cons: Difficult to downscale structured monitoring data and difficult to analyse ad hoc data.

Current state of development: Methods continue to be developed to analyse ad hoc data, but data availability for remote and difficult to access habitats like peatlands will always limit the usefulness of data such as these.

What is required for upscaling: The challenges apply more to downscaling specifically to peatland habitats.

[127] Isaac, N.J.B., van Strien, A.J., August, T.A., de Zeeuw, M.P. & Roy, D.B. (2014). Statistics for citizen science: extracting signals of change from noisy ecological data. Methods in Ecology in Evolution, 5, 1052-1060.

17. Appendix 6: Survey to participants of 2018 workshop

ClimateXChange was asked to explore the potential scope of a national peatland monitoring framework, to inform the design of a peatland monitoring process for Scotland. ClimateXChange held a workshop in 2018 to identify priorities for peatland monitoring and explored what datasets are either already in existence or may need to be developed in order to support a monitoring framework for peatland. The initial workshop identified a number of potential data sources but did not examine how these are or could be, used to inform monitoring frameworks. This survey intended to follow up on the information gathered during that event.

https://www.climatexchange.org.uk/media/3335/peatland-monitoring-framework-workshop-note-final.pdf

Questions about how the various potential indicators are measured and how these are then used to monitor change were posed using an online survey to previous workshop participants (Table 3). The number of survey returns was unfortunately very low (n=5), but it did include compound returns from major organisations with statutory obligations (SNH), universities (University of Nottingham, University of Highlands & Islands), and research or conservation bodies (John Muir Trust, Forest Research). Unfortunately, we did not receive any survey returns from organisations that carry out specialised species monitoring.

17.1 Table A6:1. Survey results – currently measured indicators

Potential indicators	How measured?	Qualitative or quantitative?	Essential (E) desirable (D)	Can reference/target states be defined?
Site-based water table level	1. amplitude and seasonality of surface motion 2. various water table depth loggers 3. dipwells 4. WALRAGs	either	E/D (useful integrator or early indicator of recovery/stress that can be linked to GHG and e.g. vegetation. In the context of restoration, it is often the desired target (i.e. raise the water table level)	No set national reference, though local undisturbed control could be used
Soil surface moisture content	1. amplitude and seasonality of surface motion 2. soil moisture loggers 3. gravimetric sampling /oven drying	either	D	No set national reference, though local undisturbed control could be used
Surface oscillation	Direct measure using InSAR	quantitative	Mixed response	No set national reference, though local undisturbed control could be used

Potential indicators	How measured?	Qualitative or quantitative?	Essential (E) desirable (D)	Can reference/target states be defined?
Direct measurement of GHG emissions	1. cylindrical non-steady-state chamber 2. by dark chambers placed on fixed collars for gas sampling time series 3. CO_2, CH_4, N_2O (eddy covariance or chamber-based)	Quantitative (though different data quality, dependent on method used)	D	No set national reference, though local undisturbed control could be used
Direct measurements of losses of carbon in water courses (colour, DOC, TOC, POC and further conversion of these to CO2/CH4)	1. monthly water collection at river sites 2. streamwater sampling and laboratory measures of TOC, DOC	quantitative	D	No set national reference, though local undisturbed control could be used
Modelled GHG emissions of photosynthetic uptake and soil emissions, using remotely sensed parameters and ground observations	Modelling of eddy covariance-derived data of GPP against MODIS observations	quantitative	D	No set national reference, though local undisturbed control could be used

Potential indicators	How measured?	Qualitative or quantitative?	Essential (E) desirable (D)	Can reference/target states be defined?
Vegetation proxies	Lidar data, aerial photos; high resolution satellite observations and interpretation of these;	qualitative	D	No set national reference, though local undisturbed control could be used
Direct emissions of airborne losses of particulate carbon (erosion)	No returns			
Estimated evapotranspiration	1. inferred based on seasonal drawdown of surface, not directly measured, or measured on high daily basis 2. eddy covariance (modelling)	Qualitative (1) or quantitative (2)	No returns	No set national reference, though local undisturbed control could be used
Vegetation/surface albedo	No returns			

Potential indicators	How measured?	Qualitative or quantitative?	Essential (E) desirable (D)	Can reference/target states be defined?
Direct measures of C accumulation	1. long term rates of peat growth 2. peat depth probing, DSM (drone), subsidence/erosion poles or points 3. repeat optical surveys	Either, dependent on method	Mixed response	No set national reference, though local undisturbed control could be used, and by definition, and active site should have net accumulation.
CSM or analogous criteria for habitats that are still wetland or restored back to wetland.	1. SNH's SCM programme for designated sites uses analogous system 2. Peatland Action assessment follows similar survey method, albeit with more extensive list of +ve and -ve indicator species 3. Deer Best Practice Guide, habitat monitoring for blanket bog guidance	Either, dependent on method	Either, dependent on method	All habitat monitoring methodologies described except the Deer BPG have set reference targets.
Farmland species abundance	No returns			

Potential indicators	How measured?	Qualitative or quantitative?	Essential (E) desirable (D)	Can reference/target states be defined?
Cover of a specific functional group of vegetation (e.g. Sphagnum cover, extent of bare peat	Very variable (e.g. % cover in quadrats, visual estimates of Domin scores, abundance scales) for plant functional types (Sphagna, Cyperacea, Ericoid shrubs, other mosses, lichens, bare peat, open water) or at the species level for plants & lichens.	Either, dependent on method	Either, dependent on method	Yes, typically near natural peat in a similar topographic setting
Earth observations coupled with classification analysis or condition modelling	1. Surface Motion (inSAR) characteristics, (different vegetation types have different surface motion characteristics) 2. UAV-based (non-linear trends in time series)	Either, dependent on method	Either, dependent on method	Yes, typically near natural peat in a similar topographic setting
Monitoring of new and historic disturbances (e.g. burning, drainage, development, peat extraction, erosion, grazing pressure)	Variable methods including visual walkovers, point surveys, transects, area/length mapping.	Either, dependent on method	Either, dependent on method	Yes, typically near natural peat in a similar topographic setting
Mammals	No returns			
Amphibians (e.g. frogs, toads)	No returns			

Potential indicators	How measured?	Qualitative or quantitative?	Essential (E) desirable (D)	Can reference/target states be defined?
Reptiles (e.g. snakes, lizards)	No returns			
Birds	No returns			
Other vertebrates	No returns			
Invertebrates (Arthropods, e.g. insects)	Large pine weevil (Hylobius abietis); carabid beetles and moths	qualitative	Dependent on whether species of conservation concern (then E)	No set national reference, though local undisturbed control could be used
Invertebrates (Molluscs, e.g. freshwater pearl mussel)	No returns			
Invertebrates (Annelids, e.g. earthworms)	No returns			
Plants	No returns			
Lower plants and fungi	No returns			
Bacteria	No returns			

Potential indicators	How measured?	Qualitative or quantitative?	Essential (E) desirable (D)	Can reference/target states be defined?
Landscape topography/connectivity	Currently no standard approach. One method uses timeseries of changing surface motion and location of distinct surface motion characteristics within landscapes ranging from mesotope scale to whole regions. Most obvious features are the definition of ecohydrological units and areas of discharge. Other methods utilise classification of UAV derived high resolution aerial imagery	quantitative	E (understanding needs to extend to a far larger scale if we are to understand limits and opportunities for peat restoration and management	there isn't a set "reference" that would capture the variability in landscape settings
Rewetting	Currently no standard approach	either	E	no standard references - pre restoration if possible

17.2 Table A6:2. SWOT analysis of (outcome) indicators of peatland condition,, based on survey returns.

Potential monitoring mechanisms	Potential reporting scale (temporal and spatial)	Database owner	Strengths	Weaknesses	Opportunities	Threats
Site-based water level monitoring	A fairly large, national scale network is now in operation via Peatland Action and others	Various	low cost, data acquired very frequently, multi-year data available for a range of sites	No national scale analysis has ever been performed to check whether coverage is adequate/ representative, data are reported relative to local controls	National framework development, baseline for future assessment of resilience	Lack of continuity, uncertainty over compatibility of data; Sometimes relies on volunteer input and well maintained, functional dataloggers
Soil moisture content	Currently lacks spatial and temporal coverage	Various research organisati ons	low cost, data acquired very frequently	No national scale analysis has ever been performed, data are usually reported relative to local controls	No returns	Untested

Potential monitoring mechanisms	Potential reporting scale (temporal and spatial)	Database owner	Strengths	Weaknesses	Opportunities	Threats
Surface oscillation	National spatial coverage, but limited temporal coverage, (only available 2015 onwards)	UoN and other universities	cheap low cost and accurate proxy for measuring all changes in the properties of a peatland	Requires calibration against known sites; Limited to a maximum motion of <1.2 cm per 6 days	National data coverage, however data needs to be checked against a wide range of well studies sites, including restoration sites. Also needs agreed target end points/ controls.	Raw data are freely available, but data analysis is complex (and potentially costly)
Direct measurement of GHG emissions	Currently lacks spatial and temporal coverage, small number of sites (clustered) and not fully representative of all peatland types	Various universities	Provides full picture of functional response (eddy covariance) or at least indication (chambers)	Not feasible to implement widely due to cost	Useful as training data for remote sensing, with some existing good examples of modelling GPP data using MODIS satellite data.	Data not always publicly available, if e.g. students do not publish results. Lack of continuity.

Potential monitoring mechanisms	Potential reporting scale (temporal and spatial)	Database owner	Strengths	Weaknesses	Opportunities	Threats
Direct measurements of losses of carbon in water courses (colour, DOC, TOC, POC and further conversion of these to CO2/CH4)	Currently lacks spatial and temporal coverage, small number of sites (clustered) and not fully representative of all peatland types	Various universitie s/ Scottish Water	No returns			
Modelled GHG emissions of photosynthetic uptake and soil emissions, using remotely sensed parameters and ground observations	Currently no standard approach agreed for recording	Universitie s/ JHI	Potentially very powerful approach that can cover national scale over extended time periods	Requires ground observations at relatively high temporal resolution and similar spatial scale for model training	National scale coverage feasible, will require collation of suitable ground observations as training data and testing	Data currently freely accessible, this could change. Insufficient investment in model training and testing.

Potential monitoring mechanisms	Potential reporting scale (temporal and spatial)	Database owner	Strengths	Weaknesses	Opportunities	Threats
Vegetation proxies	Currently no standard approach agreed to recording this	various	No returns			
Direct emissions of airborne losses of particulate carbon (erosion)	No returns	No returns though one responden t though Scottish Water(?)	No returns	No returns	Improved monitoring would improve UK GHG Inventory efforts to include new Wetland reporting.	No returns
Estimated evapotranspira tion	Currently no standard approach agreed to recording this	No returns				
Vegetation/sur face albedo	Currently no standard approach agreed to recording this	No returns				

Potential monitoring mechanisms	Potential reporting scale (temporal and spatial)	Database owner	Strengths	Weaknesses	Opportunities	Threats
Direct measures of C accumulation	Currently no standard approach agreed to recording this	No returns				
Direct measures of peat depth	Most adhere to a standard protocol	SNH, JHI	Publicly available online	Not fully collated at present, only a baseline study (no revisits)	Continue to improve the peat map of Scotland	Lack of future funding, risk of data loss with insufficient or inconsistent data management
CSM or analogous criteria for habitats that are still wetland or restored back to wetland.	Largely similar protocols, although e.g. DMG protocol is less detailed and data not collated across Deer Management Groups.	Various	Statutory reporting requirement	Largely focussed on designated areas, reporting cycles often not met in full	Consistency in survey methods	Currently under review; Lack of future funding, risk of data loss with insufficient or inconsistent data management

Potential monitoring mechanisms	Potential reporting scale (temporal and spatial)	Database owner	Strengths	Weaknesses	Opportunities	Threats
Cover of a specific functional group of vegetation (e.g. Sphagnum cover, extent of bare peat	Currently no standard approach agreed to recording this	Intensive vegetation surveys carried out for some peatland sites	No returns	Data not standardised or collated in an accessible format	Consistency in survey methods, improvements in data collection and management	No returns
Earth observations coupled with classification analysis or condition modelling	Currently no standard approach agreed to recording this	Various trials (SNH, JHI, Universitie s)	Encouraging results from various pilots.	Not yet tested at national scale beyond a single baseline study using MODIS. Ground observations often not compatible.	Further testing at national scale, using high resolution data. Development of suitable ground observations for training required.	Lack of future funding, risk of future EO data acquisition cost

Potential monitoring mechanisms	Potential reporting scale (temporal and spatial)	Database owner	Strengths	Weaknesses	Opportunities	Threats
Monitoring of new and historic disturbances (e.g. burning, drainage, development, peat extraction, erosion, grazing pressure)	Currently no standard approach agreed to recording this except within statutory monitoring.	various	No returns	Data not standardised or collated in an accessible format	Consistency in survey methods, improvements in data collection and management	Lack of future funding, risk of data loss with insufficient or inconsistent data management
Rewetting	Currently no standard approach agreed to recording this	various	Verification of rewetting activities on the ground	Data not standardised or collated in an accessible format	Consistency in survey methods, improvements in data collection and management; Contribution to UK-wide reporting on restoration effort	Lack of future funding, risk of data loss with insufficient or inconsistent data management

Potential monitoring mechanisms	Potential reporting scale (temporal and spatial)	Database owner	Strengths	Weaknesses	Opportunities	Threats
Landscape topography/connectivity	Currently no standard approach agreed to recording this	No returns	No returns	No returns	Consistency in survey methods, improvements in data collection and management	No returns

17.3 A6.3.Survey Questions

Q0. Which organisation do you represent?

Q1. Does your organisation currently hold and/or collect monitoring data for peatlands that relate to their climate regulation functions and/or their specific biodiversity?

Check any that apply.

Peatland = an area with or without vegetation with a naturally accumulated peat layer at the surface (Clarke and Joosten, 2002). In Scotland, peat soil is defined by a depth threshold of >50 cm (Soil Survey of Scotland). This definition therefore includes damaged sites, i.e. former peat-accumulating bogs and fens, but which are now farmed, extracted, built-up, or afforested land as well as areas converted to grassland vegetation.

*** Does your organisation currently hold and/or collect monitoring data for peatlands that relate to their climate regulation functions and/or their specific biodiversity?**
Check any that apply

- ☐ Water table depth and dynamics
- ☐ Soil moisture content
- ☐ Surface oscillation
- ☐ Greenhouse gas emissions by eddy covariance
- ☐ Greenhouse gas emissions by chamber technique
- ☐ Aqueous or windborne carbon losses
- ☐ Evapotranspiration
- ☐ Change in albedo
- ☐ Peat accumulation / depth
- ☐ Habitat condition
- ☐ Species abundance
- ☐ Area cover of plant species or vegetation type
- ☐ Occurrence of disturbances (e.g. burning, drainage, browsing, development)
- ☐ Area / volume of disturbances (e.g. drainage, extraction, burning, development)
- ☐ Area of rewetting
- ☐ Landscape topography / connectivity
- ☐ Other:

Q1.1. (if relevant box ticked) Condition is variably defined by different existing monitoring frameworks.

The JNCC Common Standards Monitoring (CSM) framework uses a number of criteria to assess overall habitat condition, for which target states are defined. (See Help for an example for the blanket bog CSM assessment).

Do you have an analogous system? Please explain?

Q1.2. (if relevant box ticked) If you are monitoring particular (plant) species (or families) or vegetation types, please could you let us know what these are?

Q1.2.1. (if relevant box ticked) Are you monitoring these species just on peatlands (please remember this can include any land cover as below, as long as it is on >50 cm peat)? (Yes/No)

- peatlands in use for agricultural production of crops

- afforested peatlands

- modified peatlands (converted to moorland vegetation, but on >50 cm peat)

- modified peatlands (converted by livestock grazing to extensive grassland vegetation, but on >50 cm peat)

- modified peatlands (eroded, on >50 cm peat)

- intensive grassland (fertilised and sown in, but on >50 cm peat)

- domestic peat extraction sites

- commercial peat extraction sites

- developments on peatlands (e.g. wind farms, but on > 50 cm peat)

- rewetted peatlands (please note this only includes sites with human intervention to create a rewetted state)

- near natural (e.g. undrained, no livestock, no burning) blanket bog, raised bog, or fen

Q1.3. (if relevant box ticked) Please can you tell us what peatland disturbance(s) you are monitoring?

Q2. How is this/are these indicators measured?

(drop down list with dependency on answers to Q1 and free text to describe)

Q3. Are the data captured of a qualitative or quantitative nature? (Q1 responses)

Q4. Do you feel it is essential, or desirable, to monitor (Q1 responses) in peatlands? Please explain why.

Q4.1. Subquestion if habitat condition monitoring was ticked: Which of the following subcriteria do you feel are essential in habitat condition monitoring and which aren't? Why?

Q5. For each of the monitored indicators (Q1 responses), are there reference/target states defined, against which this indicator is measured?

Yes/ no, with free text

Q6. Indicator types. For each of the indictors you are monitoring, please can you indicate what kind of indicator you think this relates to?

- Baseline indicators (i.e. those still to be developed)
- Existing indicator that can tell us something about change/trends (positive/negative relative to baseline and/or target).
- Indicators that can tell us about sustainability of current management
- Indicators useful for early warning systems
- Indicator can cover loss and damage reporting

Q.7. Would you consider the data collection (Q1 responses), to date to be representative of the particular peatland habitat that you are interested in, **across Scotland**?

Sometimes there may be a lot of data, but only from a few locations, or other times you may have a very neat and structured design, but it misses (small but critical) peatland habitats. On a temporal scale, please consider the length of the observation timeframe and potential bias, e.g. sometimes data may have been collected only in extreme years, or only in certain seasons.

Please give details in the relevant box below.

Q8. Does your organisation own or collate these data (Q1 responses),?

Own/ collate (free-text)

Q8.1. Why are these data collected? (Statutory obligations, research, commercial interest, conservation interest, other)

Q8.2. Would these data be freely accessible to build a future monitoring framework? Please could you give details?

Q9. What do you feel are the major strengths of the dataset(s) you have mentioned (Q1 responses), in relation to a potential future peatland monitoring framework?

Q10. What do you feel are the major weaknesses of the dataset(s) you have mentioned (Q1 responses), in relation to a potential future peatland monitoring framework?

Q11. Are there potential opportunities in relation to using or developing these datasets (Q1 responses), for a potential future peatland monitoring framework? If so, what would need to be done?

Q12. Are there any threats to the existence or continuation of these datasets (Q1 responses)?

Q13. Would you consider letting us keep your contact information for the sole purpose of contacting your organisation for further information in relation to data sources mentioned in the previous ClimateXChange Peatland Monitoring Framework workshop? This would only be in relation to further information about data sources that were identified pertaining to water quality, natural flood management or cultural ecosystem services, as per the previous workshop (https://www.climatexchange.org.uk/media/3335/peatland-monitoring-framework-workshop-note-final.pdf)

Q13.1. If you answered yes, please could you enter your email address?

Q14. Do you have any feedback on this survey? Please let us know if you haven't been able to tell us something that you feel is important in relation to scoping a future Peatland Monitoring Framework.

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