Peatland Case Study

Summary

Key policy messages

Immediate restoration of both upland and lowland degraded peatland is a beneficial climate change mitigation and adaptation response, with benefits likely to increase under more rapid and/or severe climate change (although precise relationships are uncertain). Possible tipping points may favour restoration of sites before they degrade rapidly, but restoration of already badly degraded sites offers immediate gains in terms of emissions avoided. However, reliance on voluntary enrolment (rather than regulatory obligations) means that the extent of restoration is affected by the availability of funding for necessary capital investments but also interactions with (especially) agricultural policy support and market returns, both in the uplands and lowlands. The latter gives rise to high opportunity costs for productive lowland sites, and poses a challenge to achieving restoration of fenlands responsible for a disproportionate share of overall peatland emissions.

What is the outcome?

The Government has an objective in the 25 Year Environment Plan (25YEP) (HMG, 2018) of 'restoring vulnerable peatlands and ending peat use in horticultural products by 2030'. This applies to all vulnerable peatland (upland and lowland). There is also an additional 25 YEP objective to restore 75% of our terrestrial protected sites to favourable condition (which would include protected peatland sites, which forms a significant percentage of upland sites but few lowland sites). The 25 YEP sets out the intention 'to create and deliver a new ambitious framework for peat restoration in England', and notes that where it is not appropriate to restore lowland peat, 'we will develop new sustainable management measures to make sure that the topsoil is retained for as long as possible and greenhouse gas emissions are reduced'.

For this analysis, a specific quantified target is needed. An England-specific restoration target and strategy for peatlands are due to be announced soon (probably 2020), but in the meantime the case study uses the targets set out in the UK Peatland Strategy (led by IUCN), which sets goals to restore one million hectares of degraded peatlands by 2020 and two million hectares by 2040. This is not a Government target, but is consistent with the 25YEP outcome. There is also a joint Ministerial Statement of Intent to enhance (i.e. increase) the natural capital represented by peatlands, and also a 25 YEP goal to manage all soils sustainably.

Restoration of degraded peatlands represents both a mitigation response and an adaptation response. In terms of mitigation, restoration can reduce existing intense emissions from actively eroding sites, and reduce the risk of less degraded sites becoming more intense sources due to further degradation. However, because climate change is anticipated to further increase emissions from degraded peatlands, restoration is also an adaptation response in that it will help to protect the carbon store against future pressures – ideally by allowing the peatland itself to adapt (e.g. shifts between plant species), but at least by making it more resistant to climate change pressures. In addition, restoration of peatland provides other ecosystem services and adaptation benefits. For example, smoothing base and peak water flows, both of which may become more erratic if rainfall patterns change, or providing a refuge for plant and animal species threatened by climate change elsewhere.

How does climate change affect the outcome, in a 2 vs 4°C pathway?

The majority of peatland sites in England are primarily in poor condition as a result of unsympathetic land management, leading to areas of bare peat, a loss of soil, habitats and biodiversity, and reduced capacity to stabilise base and peak flows of water (Dickie et al., 2015; Evans et al., 2017; Thomson et al., 2018). In this condition, climate change will increase the loss of ecosystem services from peatlands including through the risk of loss of the peat-forming sphagnum moss layer on upland peats from hotter, drier conditions. Intact, functioning peatlands may still be susceptible to climate change, but evidence suggests that they will be more resilient (to it) and may indeed be able to self-adapt (e.g. through changing their vegetation species mix) to continue functioning. The difference in impacts between 2°C and 4°C pathways is difficult to specify, but it is presumed that degradation risks and rates of degradation increase with temperature and that trigger points, such as prolonged droughts or simply more variable patterns of precipitation, may well exist for abrupt shifts in vegetation cover and erosion (Fenner & Freeman, 2011; Carey el al., 2015; Dielman et al., 2016; Li et al., 2016; Swindles et al., 2016). Ultimately, once a site approaches complete depletion of peat, degradation becomes irreversible. Before this point is reached, degradation can generally be reversed, albeit that required actions may be more expensive and take longer to take effect. This suggests that inaction now may potentially lock-in irreversible damage at some sites, and is more likely to incur additional on-going ecosystem service losses and increase later restoration costs.

What are the economic costs of climate change, i.e. the effect on the outcome?

The costs of inaction from climate change is the value of ecosystem services lost due to continuing and worsening degradation, and potential irreversible effects, with the counterfactual being the comparison between the performance of restored and unrestored sites over time i.e. the relative difference rather than absolute performance levels. Valuation of lost ecosystem services are challenging to quantify, but it is possible to use illustrative figures. For example, if non-traded central carbon values are applied to possible emission trajectories (Evans et al., 2017) for the 0.65m ha of (lowland and upland) peatland in England that would contribute to the IUCN target if restored, estimated Present Value costs of emissions by peatlands over the period to 2040 lie in the range of £13.75bn to £16.2bn. Consideration of other degradation losses further increase these estimates (Harlow et al., 2012; Glenk and Martin-Ortega, 2018)), adding perhaps £1.5bn for biodiversity losses to 2040.

What are the potential additional adaptation options to address climate impacts on the outcome?

It is apparent and well-known that there is a current problem of degraded peatlands already imposing a loss of ecosystem services upon society now, and a longer-term problem with continued and worsening degradation imposing increasing costs. Both of these can be addressed through restoration, with early action having short-term benefits as well as longer-term resilience to climate change. As such, restoration is a low-regret option (CCC, 2013). Moreover, early action is desirable given that restoration to a near-natural, fully-functional state can take decades or longer and that restoration costs increase with the degree of degradation faced.

Restoration typically requires removal of damaging pressures, most notably unsympathetic management practices, but also often remedial structural action. The latter includes blocking of drainage to raise the water table, but can also involve stabilisation and revegetation of bare peat plus reprofiling of gulleys – all of which entail capital investments upfront. Management practices also need to change in order to encourage recovery to occur once structural improvements have been made. This may take the form of changes to land use, such as with cessation of peat extraction, and/or intensity of land use, such as with reductions in livestock numbers. Changing land use, particularly in more productive lowland settings, may reduce some provisioning services (e.g. food production) but gains in other ecosystem services will generally outweigh this.

What are the benefits and potential costs of adaptation?

Comparison of the costs and benefits of restoration needs to account for relative magnitudes but also timing. In particular, capital investment costs are incurred upfront whilst benefits accumulate more slowly over time (as do any opportunity costs). This makes the choice regarding both the time period over which comparisons are made, and the discount rate by which future costs and benefits are translated to an equivalent Present Value, important. In particular, shorter time horizons and higher discount rates will diminish the apparent value of durable ecosystem services derived from a functioning peatland capable of withstanding climate change.

Nevertheless, illustrative cost effectiveness and cost-benefit analysis indicate that restoration is generally worthwhile in most (but not all) cases, for both upland and lowland peatlands. For example, reported cost-benefit ratios (Harlow et al., 2012; Moxey & Moran, 2014; Bright, 2017; CCC, 2013) for different sites range between 1.3:1 and 12:1, depending on the time-horizons and benefits considered. **Importantly, the merits of restoration increase if more ecosystem services are included. Net benefits also increase the longer the time-period considered and the greater the assumed pace and extent of climate change: climate change strengthens the case for restoration.**

Step 1. What is the outcome?

The 25 Year Environment Plan has a specific goal for 'restoring our vulnerable peatlands and ending peat use in horticultural products by 2030'. The 25YEP is not that specific on what constitutes vulnerable peatlands, but it does imply this covers all unsustainable peatland use, for upland and lowland. For the latter, it states that '*although our drained lowland peatland makes up only a small proportion of the agricultural land in England, these are among our most fertile soils and play an important part in the nation's food supply. Conventional agricultural production using current techniques on drained peatland is, however, inherently unsustainable*'. The 25YEP sets out the intention '*to create and deliver a new ambitious framework for peat restoration in England. Where it is not appropriate to restore lowland peat, we will develop new sustainable management measures to make sure that the topsoil is retained for as long as possible and greenhouse gas emissions are reduced*'. This implies that for lowland peat, either restoration or sustainable management will be advanced, but there is no indication of what the balance might be between the two, or the conditions that would favour one strategy over the other.

For the analysis in this project, a specific target is needed. An England-specific restoration target and strategy for peatlands are due to be announced by the Government soon, probably in 2020, but in the meantime the IUCN-led UK Peatland Strategy sets targets to restore one million hectares of degraded peatlands by 2020 and two million hectares by 2040; these targets are used in this case study as a basis for the cost-benefit analysis. There is also a joint Ministerial Statement of Intent to enhance (i.e. increase) the natural capital represented by peatlands. Furthermore, the 25 YEP sets out the goal to 'Improving our approach to soil management: by 2030 we want all of England's soils to be managed sustainably'.

Peatlands are a distinctive ecosystem and landscape. The peat itself is a waterlogged soil made of preserved plant material, which, over centuries can accumulate to a depth of several metres. This represents a significant carbon store (globally greater than that of trees, despite forestry covering a much greater area)[1], and hence peatlands play a role in climate regulation. Yet functioning peatlands also contribute to wider ecosystem services, including water regulation, cultural and recreational services, and food and timber provision, plus they are a unique habitat supporting important biodiversity (Bonn et al., 2016). This case study considers both lowland and upland peatlands.

Unfortunately, many peatlands are in a damaged state due to unsympathetic land management and pollution. For example, due to peat extraction for fuel or horticultural purposes, afforestation, and draining, liming, grazing and/or burning for agriculture and sporting estates, whilst nitrogen enrichment from air and water pollution (from agricultural and transport emissions) can be problematic. Such pressures can cause changes in vegetative cover and water table height, which can lead over time to areas of bare peat, loss of soil, habitats and biodiversity, and reduced capacity to stabilise base and peak flows of water; for example, drainage and over-grazing. It is stressed, however, that climate change is not a major driver of current peatland status. Recognition of the poor condition of UK peatlands has prompted increasing efforts over the past decade or so to undertake peatland restoration in an attempt to recover ecosystem services, notably under the IUCN UK Peatland Programme.[2]

Following publication of findings from the Peatland Programme's Commission of Inquiry,[3] including an ambition to restore one million hectares of degraded peatlands by 2020, a joint Ministerial

[1] ONS (2016) estimates that UK bogs contain 2306 MtC, forestry 900 MtC.
[2] http://www.iucn-uk-peatlandprogramme.org/
[3] http://www.iucn-uk-peatlandprogramme.org/publications/commission-inquiry/inquiry-findings

Statement of Intent was issued in 2013 by all four nations of the UK, committing to enhancing the natural capital represented by peatlands.[4]

Publication of the IUCN-led UK Peatland Strategy 2018 – 2040 has reaffirmed the 2020 target, but also extended this to 2m ha by 2040 and presented a vision of peatlands protected, enhanced, sustainably managed and recognised for their public value.[5] The Peatland Strategy also sets out a number of more specific objectives and actions, as summarised below.

Actions to include:

- Conserving and enhancing the best and most readily recoverable peatlands
- Restoring heavily degraded peatland to functioning, peat-forming ecosystems
- Applying land uses that are compatible with healthy peatlands
- Shifting management of drained peatlands under intensive productive use towards wetter ways of farming
- Maintaining a formal, Government supported programme to stimulate funding, share experience, promote best practice and monitor progress towards strategic goals
- Communicating peatland values, both intrinsic and measurable, to a wide audience.

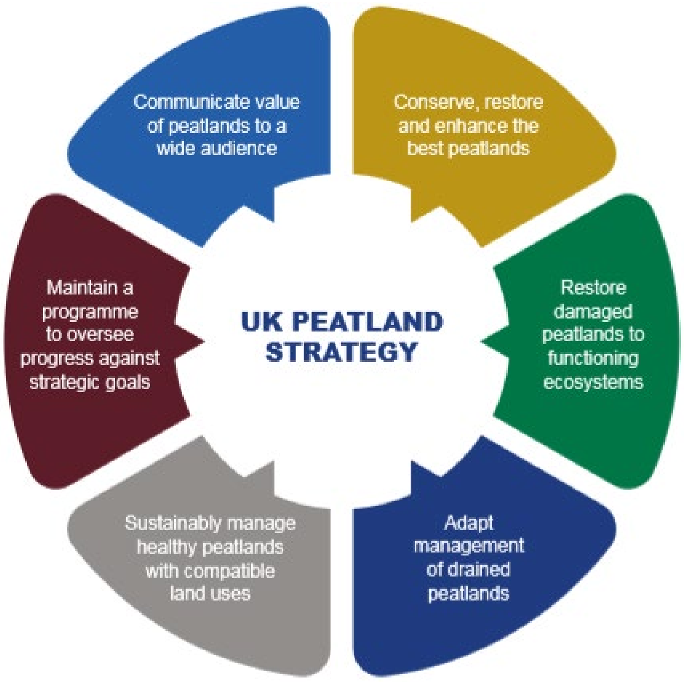

Figure 1 Peatland Strategy Objectives and Actions. S*ource: UK Peatland Strategy.*

The UK-level restoration targets are not yet disaggregated to constituent countries, so there is not currently an explicit target for restoration in England. Moreover, because different methods and definitions[6] have been used at different times in different parts of the UK, the extent and condition of UK peatlands is not known precisely. Consequently, understanding of the extent and level of degradation of peatlands across England is imperfect – although new estimates are due to be

[4]http://www.iucn-uk-peatlandprogramme.org/sites/www.iucn-uk-peatlandprogramme.org/files/20130205%20Joint%20DA%20letter%20to%20IUCN.pdf

[5] http://www.iucn-uk-peatlandprogramme.org/resources/uk-peatland-strategy-2018-2040

[6] For example, ECI et al. (2013) also note differences between peatlands defined via soil and peatlands defined by habitats. Differences also exist in relation to depth of peat required.

published in the near future. Nevertheless, there is a consensus that most lowland and upland peatlands in England (as elsewhere in the UK) are generally in a poor condition and a significant area would benefit from restoration (Dickie et al., 2015; Evans et al., 2017; Thomson et al., 2018): only 1% is estimated as being in a natural, undamaged state (Natural England, 2010) and 69% as under a peat-restricting land use (ECI, 2013).

Evans et al. (2016, 2017) and Thomson et al. (2018) estimate the UK total area of peatlands, both lowland and upland, as 2.6m to 3.0m ha, with England accounting for around 0.6m to 0.7m ha. Natural England (2010) report a similar total. This suggests that England's implied share of the overall target of restoring 2m ha by 2040 could perhaps be around 0.65m ha at most.

About 0.35m ha are upland bog, 9% of which is estimated to be over-grazed, 7% dominated by scrub or woodland, 14% hagged or gullied and 51% under low-intensity grazing. Around 0.3m ha is lowland bog or fen, around 0.19m ha (63%) of which is depleted "wasted" peat often now mixed with its underlying mineral substrate, and overall 39% is under intensive cultivation and 22% under intensive grazing (Natural England, 2010; ECI, 2013).

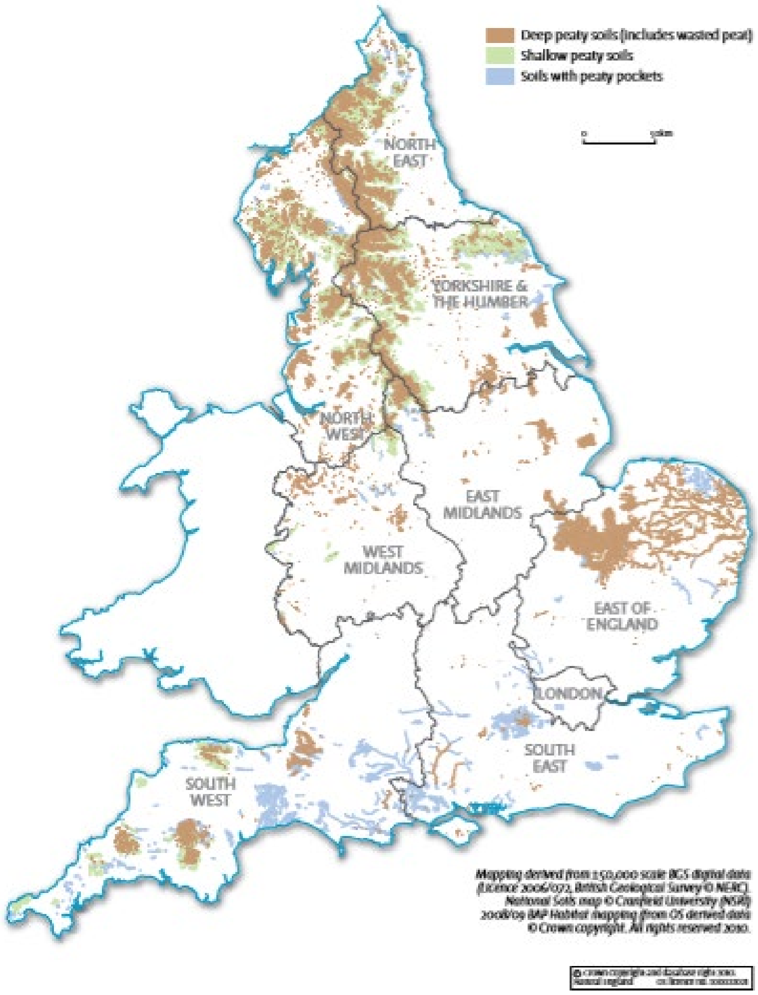

Figure 2 Distribution of peatlands in England. *Source: Natural England (2010)*

Institutionally, the UK Peatland Strategy is driven by members of the IUCN Peatland Programme (principally national and local NGOs), but with significant interaction with Government agricultural and environmental departments and environmental agencies (i.e. in England- Defra, Natural England and The Environment Agency) plus water companies (e.g. South West Water, United Utilities). Given the dominance of privately-owned land, it is also highly dependent on how private land managers respond to policy and market signals. It is likely that any England-specific peatland strategy will closely follow the logic and ambitions of the UK strategy.

Although not expressed formally as a Theory of Change, the inferred logic model underpinning the UK Peatland Strategy is relatively clear, falling into three stages; first, funding (*the input*) of awareness raising, training and on-the-ground activities (*the processes*) will enable restoration to take place; second, the area of restored and therefore good-condition peatland will increase (*the output*); and third, fuller ecosystem functionality will return (*the outcome*).

The link between inputs and outputs assumes that restoration activities are appropriate and implemented correctly, which can be encouraged through guidance and the sharing of best practice (which has been promoted by the IUCN and its partners[7]). The logic link also assumes that degraded peatlands will not recover without at least some explicit restoration activity and that the value of the recovered ecosystem services will exceed the costs of restoration, representing an investment-to-save in most (but not necessarily all) cases (e.g. Moxey & Moran, 2014; Glenk & Martin-Ortega, 2018).

The link between outputs and outcomes depends on the time taken for restoration to become effective, the relationship between ecosystem condition and ecosystem service delivery and the durability of restoration – recovery may be slow and subject to external pressures, such as climate change or land use change, which could potentially reduce or reverse any recovery. Hence, whereas there is good, and increasing, evidence about the appropriateness and short-term effectiveness of different restoration techniques, the precise timing, magnitude and durability of ultimate ecosystem service outcomes is subject to some uncertainty.

Nevertheless, restored sites are generally expected to out-perform unrestored sites in terms of ecosystem delivery. In particular, it is expected that climate change will accelerate further degradation of already damaged peatlands, leading to them losing yet further ecosystem services, but that restoration will halt or at least slow further degradation and hence better preserve valuable ecosystem services. This perspective has previously been expressed by the Adaptation Committee: 'Without further action it is likely that the current level of degradation will increase with climate change. Instead of providing vital and valued services, peatlands will increasingly cause costly problems to society'.[8] To support this, Glenk et al. (2018) report public support for early rather than delayed restoration action and CCC (2018) reports higher benefits from anticipatory rather than reactive restoration for a case study at Moorhouse and Upper Teesdale.

Because the majority of ecosystem services delivered by functioning peatlands take the form of non-market benefits, there is a need to raise awareness of their public value and to commit to long-term public funding of their restoration and preservation (although opportunities for private funding should also be explored, for example through the Peatland Code[9]). This requires efforts to educate members of the public, land managers and policy makers, and to share experiences amongst the peatland community of how restoration can be valued and achieved cost-effectively.

There is no formal theory of change for the outcome, but an illustrative logical framework is shown below.

[7] e.g. http://www.iucn-uk-peatlandprogramme.org/publications/demonstrating-success/uk-peatland-restoration-demonstrating-success; http://www.moorsforthefuture.org.uk/blanket-bog-land-management-guidance

[8] Page 88 of https://www.theccc.org.uk/wp-content/uploads/2013/07/ASC-2013-Book-singles_2.pdf

[9] http://www.iucn-uk-peatlandprogramme.org/peatland-code

ACTIVITIES
Creating the enabling environment and regulatory framework to support the restoration of peatlands

↓

OUTPUTS
Policies and measures are in place to incentivise restoration and ensure sustainable management

↓

OUTCOME
Peatlands are restored and are managed sustainably, reducing greenhouse gas emissions

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IMPACT
England's peatlands are healthy and provide a wide range of ecosystem services, in a sustainable way

Figure 3. Illustrative Logical model for Peatlands

Step 2. How does climate change affect the outcome, in a 2 vs 4°C pathway?

Degraded peatland conditions interact with year-on-year variability in weather to increase the risks of, for example, wildfires, wind and water erosion (all of which release stored carbon, but also reduce habitats and biodiversity as well as diminishing cultural and recreational value), and unpredictable downstream flows of water plus discolouration of water. The latter arise from the reduced capacity of degraded peatlands to store and gradually release water to maintain baseflow, but more dramatically from the reduced capacity of degraded peatlands to slow the pace of (in particular) surface water runoff and hence regulate peak flows and reduce flood risks.[10]

Intact, functioning peatlands may be susceptible to climate change, through a combination of warming temperatures and shifts in the timing and intensity of precipitation. In particular, warmer, drier summers are more likely to expose peatlands to drought, potentially leading to desiccation. This may increase the risk of wildfire damage plus wind erosion and, once rainfall does return, water erosion. In addition, there is some evidence that warmer temperatures and fluctuating water tables increase microbial activity to release stored carbon.

The distinction in impacts on peatlands between 2°C and 4°C climate scenarios is difficult to specify, but it is presumed that degradation risks and rates of degradation will increase with temperature and that trigger points, such as prolonged droughts or simply more variable patterns of precipitation may well exist for abrupt shifts in vegetation cover and erosion (Fenner & Freeman, 2011; Carey el al., 2015; Dielman et al., 2016; Li et al., 2016; Swindles et al., 2016). Ultimately, once a site approaches complete depletion of peat, degradation becomes irreversible, although rewetting may still preserve any remaining peat and mitigate emissions. This probably already applies to much of existing "wasted" fenland peat, and any rapidly eroding sites are at risk of the same. However, until this point is reached, degradation can generally be reversed, albeit that required actions may be more expensive and take longer to take effect. This suggests that inaction now may potentially lock-in irreversible damage at some sites, but is more likely to simply incur additional on-going ecosystem service losses and increase later restoration costs.

Changing patterns of temperature and precipitation are also predicted to shift the geographical range of suitability for peatlands. In the UK, this is highlighted by bioclimatic simulations which suggest that

[10] Although it should be noted that downstream impacts are also dependent on how other parts of the catchment are managed and the extent to which water courses have been modified.

sites in the south and east will be under the greatest climate pressure, with suitability shifting north and west to shrink the suitable space by over 80% (Clark et al., 2010; Gallego-Sala et al., 2010).

However, bioclimatic suitability does not determine the fate of existing peatlands because functioning peatlands are resilient ecosystems able to (up to a trigger point) withstand pressure for change (Gallego-Sala & Prentice, 2013). This occurs through tolerance of and recovery from short-term ("pulse") shocks, such as fires, and through self-adaptation to longer-term ("press") pressures such as climate change; paleo-ecological evidence suggests that peatlands can survive and even thrive if the species mix within plant communities has an opportunity to adjust (Parish et al., 2008; Robroek et al., 2017).

The extent to which intact peatlands will be able to withstand future climate change is unknown, and much depends on the pattern of seasonal changes in temperatures and precipitation as well as aggregate changes. Whilst it is hoped that restored peatlands will be able to withstand climate change pressures, it is possible that they will not and that their condition and associated provision of ecosystem services will decline over time. However, in either case, degraded peatlands will be less resilient and will experience more rapid deterioration in ecosystem service delivery than functioning peatlands.

Consequently, the appropriate counterfactual comparison is between the performance of restored and unrestored sites over time i.e. the relative difference rather than absolute performance levels. This depends on the relative rates of degradation, which can be characterised simplistically as the difference in slopes on a graph. For example, Figure 4 illustrates possible trajectories for GHG emissions for an unrestored site and a restored site under two scenarios.

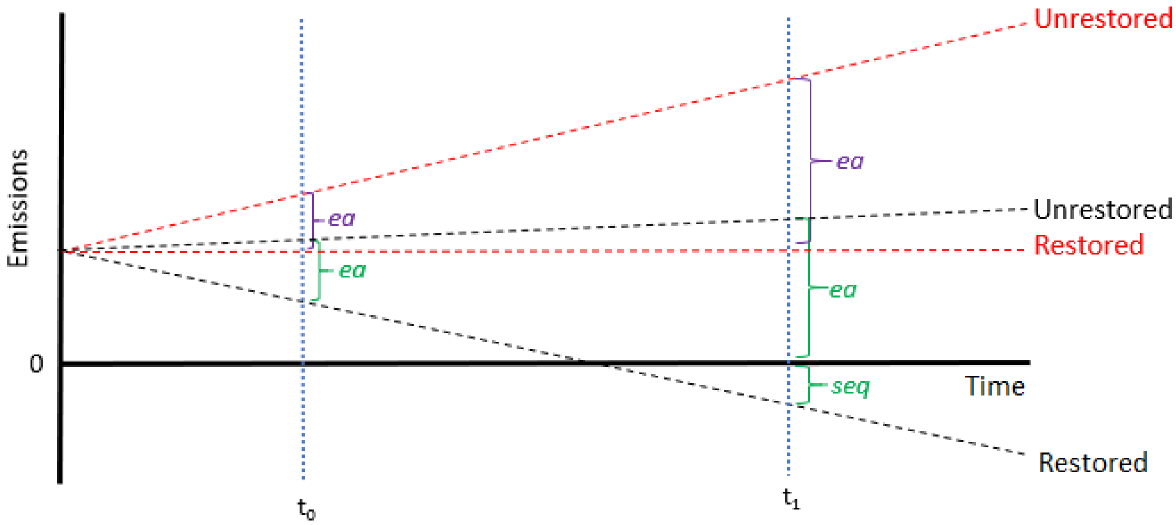

Figure 4 Stylistic emission trajectories for unrestored and restored peatland sites

The black dotted lines represent a scenario in which emission losses continue to increase gradually over time from the unrestored site, but decrease over time for the restored site and eventually become negative as net sequestration is achieved. The difference between the two lines widens (e.g. t_0 to t_1) over time, reflecting both the increase in emissions avoided (ea) by restoration and eventually net sequestration (seq). This scenario perhaps reflects conditions under modest climate change, with restored sites able to withstand climate pressures.

The red dotted lines, pivoting upwards from the same starting point on the vertical axis, represent a scenario in which degradation of the unrestored site proceeds at an even faster rate and restoration only halts rather than reversing degradation. Again, the difference between the two lines widens over time, but the benefit of restoration is solely in terms of emissions avoided (ea) rather than any net sequestration. This scenario perhaps reflects conditions under more moderate climate change, with already damaged sites suffering accelerated degradation and restoration unable to do more than halt further degradation. More severe climate change would be represented by a further upward pivot, with even restored sites suffering continued degradation.

The slopes, and indeed shapes, of the lines are highly uncertain.[11] For example, they may be non-linear, particularly if there are threshold (trigger) points beyond which rapid degradation is likely and/or new sequestration plateaus at a low level, or restoration takes time to become fully effective Moreover, given finite depths of peat, emission from a degraded site will ultimately drop to zero when the resource has been lost. However, if attention is confined to the typical time horizons of 25 to 40 years used for economic analysis, simplistic linear trajectories can serve as a first-approximation of impacts.

Figure 5 is presented in relation to GHG emissions because, despite various uncertainties, there is better quantitative information for restoration effects on emissions than on other ecosystem services and, moreover, published carbon values can be used to estimate restoration benefits. However, a similar conceptual approach can be used for other ecosystem services, with the restored line being above the unrestored one and the difference between them representing the benefit (see Figure 5).

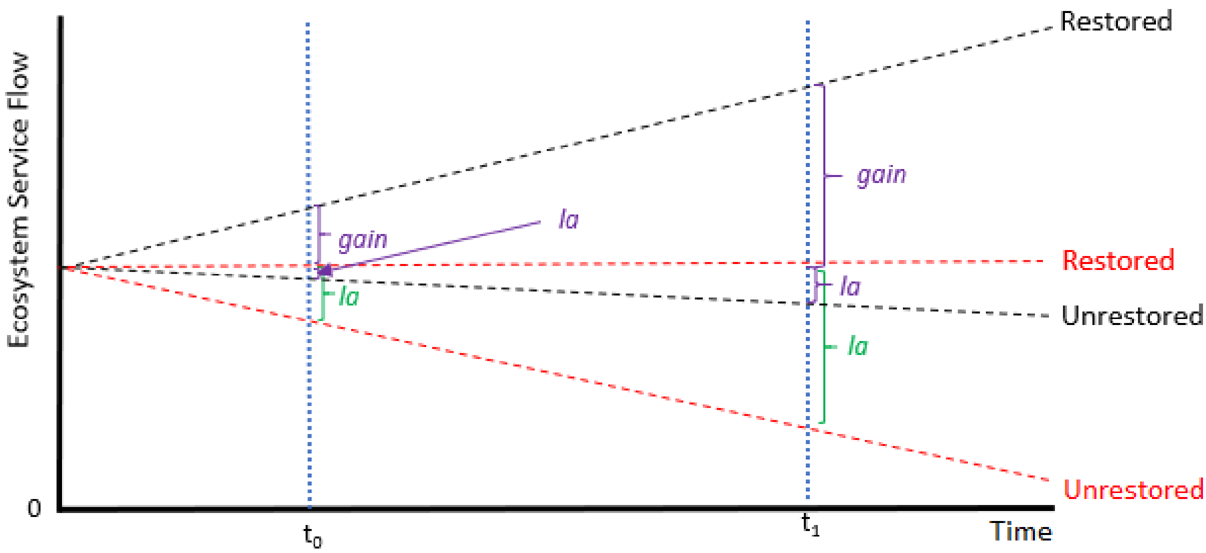

Figure 5 Stylistic trajectories for other ecosystem service flows from peatland sites

Again, the black dotted lines represent a scenario in which ecosystem service flows continue to decline gradually over time from the unrestored site whilst increasing for the restored site, with the difference between them comprising a combination of losses avoided (la) and actual gains (gain). The red dotted lines represent a scenario in which the rate of loss is accelerated for the unrestored site and degradation is only halted, not reversed, at the restored site. In this case, the difference between them is simply losses avoided (la), but still increases over time. A more severe climate change scenario could be represented by a further downward pivot of the red dotted lines, with even restored sites experiencing a decline in service flows over time. As with emissions, the slope and shape of the lines is highly uncertain, but linear approximations can serve to illustrate relative impacts over the short to medium-term.

[11] On-going modelling efforts will improve understanding of likely trajectories, for example “DigiBog” https://water.leeds.ac.uk/our-missions/mission-1/digibog/

Step 3. What are the economic costs of climate change, i.e. the effect on the outcome?

The costs of inaction are the value of ecosystem services lost due to continuing and worsening degradation. Information on these costs is increasing as more studies are published, yet remains relatively scarce. Consequently, given heterogeneity of site conditions and current management, it is difficult to estimate aggregate costs. Nevertheless, it is possible to use illustrative figures to give an indication.

In relation to climate regulation services, the Peatland Code provides estimates of GHG emissions for different categories of degraded upland peatlands, ranging from around 2t CO_{2e}/ha/yr for lightly degraded sites through to around 24t CO_{2e}/ha/yr for actively eroding bare peat, with emissions from intensive cultivation or grazing of lowland peats being around 18 to 24t CO_{2e}/ha/yr (Graves & Morris, 2013; Smyth et al., 2015; Evans et al., 2016).[12]

Evans et al. (2017) estimate current annual emissions for English peatlands as around 11mt $CO_{2e.}$ If published non-traded central carbon values[13] and the standard 3.5% discount rate are applied to these, the implied Present Value costs to 2040 are around £13.7bn without further degradation. If climate change causes annual emissions to increase by 0.5% to 1.5% per year (after CCC, 2013: Figure 4.6), costs would rise to between £14.5bn and £16.2bn respectively. There figures are, of course, sensitive to a number of underlying assumptions but give an indication of the possible magnitude of degradation costs. Arguably, under a 4°C+ scenario, rapid degradation of all unrestored sites might be expected to be triggered, pushing emissions to the upper-bound estimates more quickly and hence increasing overall carbon costs. In addition, given that current carbon price projections relate to 2°C scenarios, overall costs would presumably increase through unit-price effects as well as overall emission levels (but no such price projections appear to have been calculated).

Climate regulation is only one of the ecosystem services offered by peatlands, and one of the Peatland Strategy objectives is to raise awareness of the value of these and indeed on how to value them.[14] However, in the absence of published official unit values, valuation of other services has to rely upon relatively scarce academic studies deploying a range of non-market valuation techniques. Several of these have now been conducted within the UK and provide estimates for a broader range of ecosystem services, including water regulation, landscape, recreational and biodiversity, as well as climate regulation.

For example, Harlow et al. (2012) use values provided by Christie et al. (2011) to derive degradation losses of £275/ha per year for blanket bogs, relating mainly to climate and water regulation, but also cultural and biodiversity losses.[15] More recently, Glenk & Martin-Ortega (2018) estimated annual restoration benefits which can be crudely interpreted as implying annual degradation costs of the same magnitude.[16] Applying an illustrative figure of £280/ha/yr to the 0.65m ha target ceiling area through to 2040 implies a Present Value loss of around £2.7bn, or £2.8bn to £3.0bn if degradation continues.

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[12] See also http://www.iucn-uk-peatlandprogramme.org/sites/www.iucn-uk-peatlandprogramme.org/files/PC_Emissions_Calculator_v1.1.xls

[13] £60/t in 2020, £135/t in 2040 - see DECC guidance at https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/48108/1_20100120165619_e____carbonvaluesbeyond2050.pdf

[14] For examples of how this is being attempted, see https://www2.see.leeds.ac.uk/peatland-modules/index.php?type=learning and https://icasp.org.uk/resources/peat-resources/

[15] Interestingly, Christie et al. (2011) suggest negligible costs of further fenland degradation due to already limited service provision.

[16] Specifically, if valuation of improvements from bad to intermediate to good condition are assumed to be symmetrical with valuation of losses from good to intermediate to bad, which may not be the case.

The fact that, despite including wider ecosystem services, these estimates are towards the lower-end of the carbon-only cost estimates highlights potential inconsistencies between different approaches, partly due to imperfect scientific understanding and partly due to difficulties in ensuring public understanding of complex systems (Byg et al., 2017; Martin-Ortega et al., 2017). Indeed Christie et al. (2011) note that almost no cost was perceived by participants in their study for degradation of fenland ecosystem services.

Partly to address aggregation inconsistencies, Harlow et al. (2012) attempted to unbundle the overall degradation burden, suggesting an annual cost of £152/ha for biodiversity loss alone. If this is treated as an addition to the carbon-cost calculated above, it suggests a Present Value of further costs to 2040 of £1.5bn to £1.7bn. Including other separable costs would be expected to increase overall estimates of degradation losses, but further research is needed to refine such an approach.

Step 4. What are the potential additional adaptation options to address climate impacts?

The 25 YEP sets out the intention to create and deliver a new ambitious framework for peat restoration in England (HMG, 2018). Where it is not appropriate to restore lowland peat, it identifies the need to develop new sustainable management measures to make sure that the topsoil is retained for as long as possible and greenhouse gas emissions are reduced. It also sets out to pursue work already under way to restore peatlands. There is also a commitment to publish an English peat strategy. Restoration has also already been recognised as an important policy response by the Committee on Climate Change (CCC 2017 & 2018).

Restoration of degraded peatlands represents both a mitigation response and an adaptation response. In terms of mitigation, peatlands act as storage for a considerable amount of carbon that if released would significantly add to the challenge of reducing overall emissions. Restoration can mitigate existing intense emissions from already actively eroding sites, and reduce the risk that less degraded site become intense sources through further degradation.

Protecting the accumulated store of carbon will contribute to attempts to limit the extent of climate change. However, because climate change is anticipated to increase the emissions from degraded peatlands, restoration is also an adaptive response in that it will help to protect the carbon store against future pressures – ideally by allowing the peatland itself to adapt (e.g. shifts between plant species), but at least by making it more resistant to climate change pressures.

Yet restoration also delivers other ecosystem service benefits, including water regulation and cultural/recreational services, plus to supporting habitats and biodiversity, both now and under climate change. For example, a functioning peatland contributes to downstream water regulation in terms of smoothing base and peak flows, both of which may become more erratic if rainfall patterns change, and to water. This adaptation benefit extends to other ecosystem services, quality.[17] Equally, restored peatlands will provide a refuge for plant and animal species threatened by climate change elsewhere, including contributing to potential relocation along habitat networks. Moreover, because functioning peatlands are potentially able to self-adapt to climate change, early restoration now will hopefully increase future resilience to deliver durable benefits. As such, restoration is a low regret option.

Adaptation decisions regarding restoration fall into three (inter-related) categories: which sites to restore; when to restore them; and how to restore them. The last of these is informed by practical

[17] Water companies are increasingly recognising the merits of reducing peatland emissions at source rather than treating its effects downstream. e.g. see http://www.scottishwater.co.uk/about-us/publications/strategic-projections/copy-of-business-plan-appendices-2015-2021

experience over the past couple of decades, and depends on site conditions rather than assumed climate change pressures.

Restoration typically requires removal of damaging pressures, most notably unsympathetic management practices, but also often remedial structural action. The latter includes blocking of drainage to raise the water table, but can also involve stabilisation and revegetation of bare peat plus reprofiling of gulleys.

Management practices need to change in order to encourage recovery to occur once structural improvements have been made. This may take the form of changes to land use, such as with cessation of peat extraction, and/or intensity of land use, such as with reductions in livestock numbers. The costs incurred by this take the form of opportunity costs, of foregone outputs from commodity production (part of the ecosystem service of "provisioning").

By setting ambitious targets, the UK Peatland Strategy implies that most degraded peatland should be subject to restoration, regardless of its current degree of degradation. However, given that restoration takes time and the capacity (e.g. specialist equipment and skills) to undertake it is limited, there are various barriers to achieving this. To an extent, if enrolment in restoration activity remains a voluntary act, the level of action will be guided by the willingness of land managers to engage with restoration programmes. This, in-turn, will be influenced by the availability of funding for both upfront capital works and ongoing management or opportunity costs.[18] Yet this may not be optimal in terms of targeting effort for maximum effect (i.e. net benefits) and once better information becomes available on the distribution of different condition categories of peatlands, consideration should be given to the likely trajectories of different sites under different climate change scenarios and hence the relative urgency of restoring them.

Most restoration activity to-date (which by no means covers all degraded sites) has been in upland areas, reflecting that opportunity costs are (in general) comparatively low (Moxey, 2016). That is, the predominant land use of extensive livestock grazing is relatively unproductive, and mostly dependent on public support. This means that the value of any displaced production[19] is limited, and generally outweighed by gains in other ecosystem services, with available funding potentially sufficient to incentivise voluntary enrolment in restoration by some (but not all) land managers.

By contrast, intensive grazing and arable or horticultural cultivation of lowland peats is often highly productive and typically incompatible with restoration. Although shifts to lower intensity grazing or alternative non-food crops (paludiculture)[20] are potentially technically feasible, the opportunity cost of loss of market income can be substantial.

Yet emission losses from degraded lowland peats are high, and the sustainability of current land use patterns is questionable given possible negative effects of continued soil loss and anticipated climate change on productivity (Graves & Morris, 2013). Evans et al. (2016: p4) suggest that "Reducing emissions from cultivated peatlands would almost certainly make a larger contribution to reducing total emissions than blanket bog restoration on a per hectare basis, and could generate significant emissions savings at a UK scale if financial and policy incentives to support improved agricultural management of lowland peatlands were put in place."

Current policy approaches to restoration are centred on voluntary enrolment, either under the auspices of the Common Agricultural Policy (CAP), most obviously through agri-environment schemes, and/or parallel, peatland-specific programmes. These are administered by Government bodies, but

[18] For the latter, if land managers perceive restoration as imposing private opportunity costs arising from a loss of existing support payments

[19] Actual displacement due to (e.g.) lower stocking densities and/or increased disease problems is highly uncertain in upland areas, with potential productivity gains also possible (Moxey, 2016).

[20] See Bonn et al. (2016) & Wichtmann et al. (2016).

often implemented through NGOs and in some cases actively supported by private water companies seeking to reduce the effects of degradation on perceived drinking water quality.

Although enrolment has been increasing, a step-change will be required to achieve the ambitious targets stated in the Peatland Strategy, either through additional funding of voluntary enrolment and/or invoking an element of regulatory obligation. However, whilst invoking the polluter-pays-principle could perhaps oblige owners of degraded peatlands to undertake restoration, this would be politically difficult. Instead, the emphasis has been on seeking additional public funding and (through the Peatland Code) private funding.

Post-Brexit, Defra's stated intention to focus on "public money for public goods" is compatible with a focus on wider ecosystem services and abolishment of CAP direct area payments will remove a commonly perceived barrier to enrolment in the form of loss of eligibility for other support (Moxey, 2016). Indeed, loss of generic support in upland areas is likely to lead to lower agricultural production and perhaps greater acceptance of wider ecosystem perspectives.

In lowland areas, by contrast, reliance on the CAP is much lower and market returns represent a much higher proportion of agricultural income. Consequently, unless more substantial compensation payments are offered to entice, or regulatory obligations are imposed upon, land managers to enrol in restoration activities, the area of restored lowland peat is likely to remain low.

The development of alternative commercial land uses on lowland peat could help to off-set foregone production, but since restoration requires raising the water table, the range of potential alternative enterprises is relatively limited. Extensive grazing is feasible, but typically has very low margins, as do biomass crops, which implies a need for some form of public funding.

Separately, consideration also needs to be given to whether cessation of current production on lowland peats would simply displace environmental degradation to other locations to satisfy continuing consumer demand for the commodities involved (Ferré, 2017).

Framework for adaptation pathways

For this case study, we have extended the list of options above to a high-level adaptation pathways framework. This uses the framework below from CCRA3. This has focused on:

- Early low and no regret options that address current risks and build resilience;
- 'Climate-smart' incl. decision making under uncertainty (for early decisions with a long life-time / risk of lock-in);
- Early planning / iterative adaptive management, in cases where there are benefits from early activities / or adaptation that involves long-lead times.

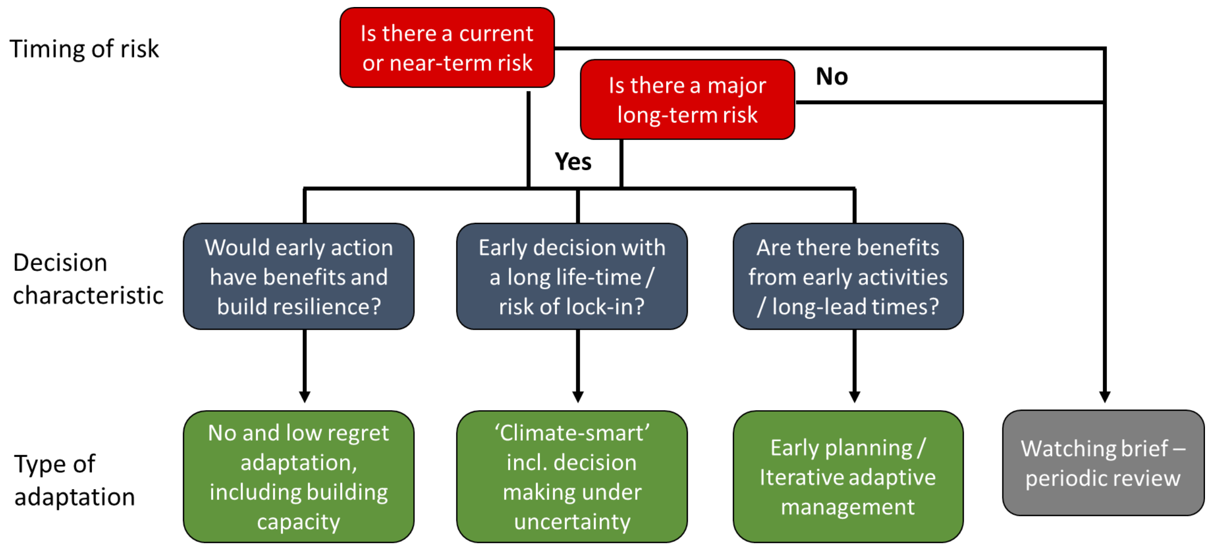

Figure 6 Early priorities for adaptation. Source CCRA3.

It is apparent that there is both a current problem of degraded peatlands already imposing a loss of ecosystem services upon society now (notably in terms of climate regulation but also other service flows) and a longer-term problem with continued and worsening degradation imposing increasing costs. Both of these problems can be addressed through restoration, with early action having short-term benefits (notably avoided emissions) but also longer-term resilience to climate change. As such, restoration is a low-regret option. Moreover, early action is also desirable given that restoration to a near-natural, fully-functional state can take decades or longer. Decisions not to restore potentially risk lock-in to irreversible degradation in some locations, but restoration itself does not necessarily lead to lock-in since it is possible to re-drain bogs and fens if (unlikely as it seems) an alternative land use was deemed desirable at some point in the future. The potential durability of restored, functioning peatlands offers extremely long-term adaptation benefits, but full realisation of these may take decades (or longer).

Step 5. What are the benefits and potential costs of adaptation?

Comparison of the costs and benefits of restoration needs to account for their relative magnitudes, but also their timing. In particular, capital investment costs are incurred upfront whilst benefits accumulate more slowly over time (as do any opportunity costs). This makes choices regarding both the time period over which comparisons are made and the discount rate by which future costs and benefits are translated to an equivalent Present Value important. In particular, shorter time horizons and higher discount rates will diminish the apparent value of durable ecosystem services derived from a functioning peatland capable of withstanding climate change.

In addition, estimates of both the costs incurred and the benefits yielded by restoration are imperfect, and hence any analysis is subject to some uncertainty. Nevertheless, as an illustrative example, applying a 3.5% discount rate, if a practitioner's rule-of-thumb figure of £1000/ha[21] for average upfront costs is assumed, then over a 20-year period to 2040, a positive benefit:cost ratio would require annual net benefits (i.e. after any on-going costs) to be over £75/ha. Harlow et al. (2012) and Glenk & Martin-Ortega (2018) estimated annual benefits at over £400/ha, which would allow for ongoing annual costs for any required management or forgone production to be up to about £325/ha. If upfront costs were lower at £500/ha, as perhaps for a lightly degraded site, ongoing costs would need to above £360/ha to yield a negative result. Estimates of ongoing costs for upland sites are

[21] Which is broadly consistent with more formal estimates reported by, for example, Artz et al. (2018) and Okumah et al. (2019)

typically lower than this, suggesting that upland restoration is worthwhile (Moxey & Moran, 2014). Similarly, if restoring 0.35m ha of upland bog cost c.£ 350m upfront, this would leave the balance of between c.£0.8bn and c.£10bn as the Present Value of avoided emissions to cover any on-going management and opportunity costs.

These crude, illustrative calculations are consistent with more formal attempts at cost-benefit analysis, with stronger results being obtained when a wider range of ecosystem services are considered and if the longer-term accrual of benefits is considered, particularly if predicted climate change effects are included (Grand-Clement et al., 2013; Moxey & Moran, 2014; Smyth et al., 2015).

Hence, for example, Harlow et al. (2012) estimated a benefit:cost ratio of between 1.3:1 and 2.9:1 over a 25 year period for a site in Yorkshire, Pettinotti (2014) estimated ratios of up to 4.9:1 for Scottish sites over the period to 2080 under climate change, the Natural Capital Committee reports 4:1 as typical and Bright (2017) estimated 9:1 for a 100 year period or 12:1 for a 300 year period for Exmoor. Such results highlight spatial variability due to site-specific factors as well as precise methodological approaches, but do demonstrate the general economic merits of restoration. This confirms the rationale for allocating funding to restoration activities, at least for upland sites.

An alternative way of illustrating this type of analysis is shown in Figure 7 (for upland peat). Each vertical blue column represents the difference between the Present Value of estimated on-going benefits and on-going costs of restoration under a given climate change scenario. The height of the column reflects possible variation in the net present value of benefits according to whether high or low unit costs and high or low unit benefits are assumed.

In all cases, the net on-going benefits are positive, but increase with the assumed severity of climate change. However, upfront capital costs also need to be considered and are shown by the pink horizontal bar. Where the horizontal pink bar overlaps with the base of a vertical blue column, total costs exceed benefits and restoration is not economically cost-effective but where the blue column extends above the pink bar, restoration is merited. This indicates that restoration, which may be desirable on ecological grounds, may not be merited economically for all sites. It also, however, highlights how climate change increases the economic rationale for restoration across all sites: more rapid and/or severe climate change strengthens the case for restoration.

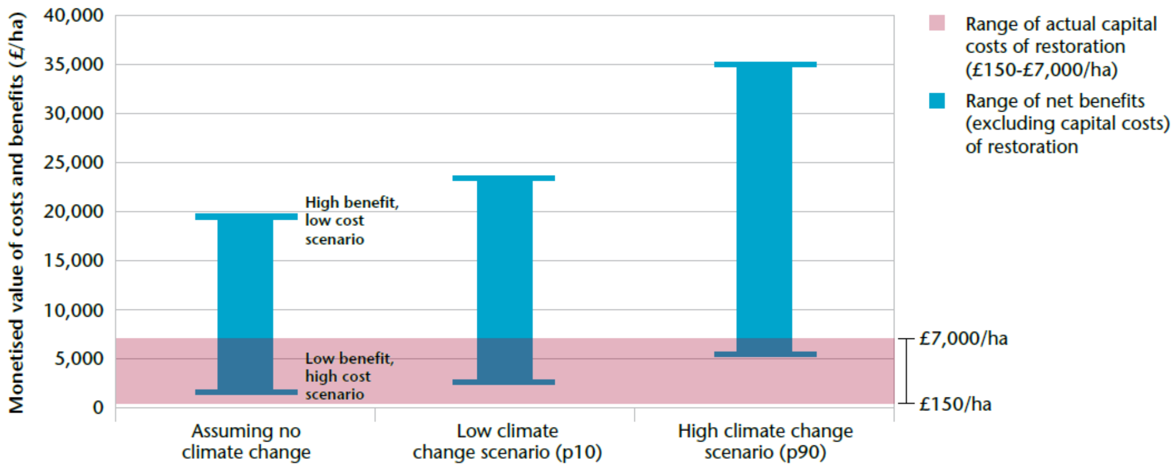

Figure 7 Summary comparison of costs and benefits of restoration for upland peat, under climate change scenarios. S*ource: Committee on Climate Change, 2013.*

The case for restoring lowland peats is, however, less straightforward than for upland sites. Whereas upland areas are relatively unproductive in terms of the commercial value added[22] arising from extensive grazing systems, lowland sites are currently highly productive agriculturally. Consequently, there is a greater trade-off to be made between the value of current and more easily observed outputs arising from degradation-inducing ("peat-consuming") land use and the value of wider, but less easily observed, ecosystem services recovered through ("peat-conserving") restoration and land-use (Wichtmann et al., 2016).

Graves & Morris (2013) and Evans et al. (2016, 2017) highlight the high GHG emission losses arising from intensive cultivation and grazing on lowland peats, reductions in which would have significant non-market value. For example, Grave & Morris (2013) estimate the value of carbon emission losses at between about £250/ha and £440/ha. Yet, Graves & Morris (2013) also estimate the accompanying current net margins of agricultural production at between £500 and £1600/ha, more than sufficient to generate a negative net ongoing benefit and hence an overall negative benefit:cost ratio, even before considering upfront capital costs.

However, Graves & Morris (2013) go on to suggest that climate change will increase annual lowland carbon losses over time, raising annual degradation costs to between £700 and £1300/ha, whilst also lowering agricultural net margins to £150/ha or less, meaning that restoration benefit:cost ratios do turn positive in the longer-run. This indicates that at some point lowland restoration will become worthwhile, and therefore that a longer time-horizon than that considered by land managers needs to be adopted. However, by the time this is more demonstrably and publicly apparent, it may be too late to instigate restoration since the damage may be irreparable. As such, lowland peats neatly illustrate the wider challenges of achieving sustainability (Frankel, 2018) and raise issues around the choice of voluntary enrolment in restoration schemes vs. regulatory obligations to restore.

Policy conclusions

Immediate restoration of degraded peatland is a useful climate change mitigation and adaptation response, with benefits likely to increase under more rapid and/or severe climate change (although precise relationships are uncertain). Possible tipping points may favour restoration of sites before they degrade rapidly, but restoration of already badly degraded sites offers immediate gains in terms of emissions avoided. However, reliance on voluntary enrolment (rather than regulatory obligations) means that the extent of restoration is affected by the availability of funding for necessary capital investments but also interactions with (especially) agricultural policy support and market returns. The latter gives rise to high opportunity costs for productive lowland sites, and poses a challenge to achieving restoration of fenlands responsible for a disproportionate share of overall peatland emissions.

References

ASC (2013) Managing the Land in a Changing Climate. Chapter 4: regulating Services – upland peat. Adaptation Sub-Committee. https://www.theccc.org.uk/wp-content/uploads/2013/07/ASC-2013-Book-singles_2.pdf

Artz, R., Faccioli, M., Roberts, M. & Anderson, R. (2018) Peatland restoration – a comparative analysis of the costs and merits of different restoration methods. Climate Exchange Report. https://www.climatexchange.org.uk/media/3141/peatland-restoration-methods-a-comparative-analysis.pdf

Bonn, A., Allott, T., Evans, M., Joosten, H., Stoneman, R. (eds, 2016) Peatland Restoration and Ecosystem Services Science, Policy and Practice. Cambridge University Press. 493 pp.

[22] There are, of course, some non-market cultural, landscape and habitat values associated with upland farming, but these are not necessarily displaced by restoration and indeed may be sustained more directly through support systems targeted explicitly at the provision of pubic goods.

Bright, G. (2017) Natural Capital Restoration Project Report. ONS. report

Byg, A., Martin-Ortega, J., Glenk, K., Novo, P. (2017) Conservation in the face of ambivalence – public perceptions of peatlands as 'the good, the bad and the ugly'. Biological Conservation 206, 181-189

Carey, P. D., Griffiths, G. H., Vogiatzakis, I. N., Butcher, B., Treweek, J., Charlton, M. B., Arnell, N. W.,Sozanska-Stanton, M., Smith, P. and Tucker, G. (2015) Priority habitats, protected sites and climate change: three investigations to inform policy and management for adaptation and mitigation. DEFRA CR0439. http://randd.defra.gov.uk/Default.aspx?Module=More&Location=None&ProjectID=16732

CCC (2017) UK Climate Change Risk Assessment 2017 Evidence Report. Chapter 3: Natural environment and natural assets. Committee on Climate Change, London. https://www.theccc.org.uk/wp-content/uploads/2016/07/UK-CCRA-2017-Chapter-3-Natural-environment-and-natural-assets.pdf

CCC (2018) Land use: Reducing emissions and preparing for climate change. Committee on Climate Change, London. https://www.theccc.org.uk/wp-content/uploads/2018/11/Land-use-Reducing-emissions-and-preparing-for-climate-change-CCC-2018.pdf

Christie M, Hyde T, Cooper R, Fazey I, Dennis P,Warren J, et al. (2011) Economic valuation of the benefits of ecosystem services delivered by the UK biodiversity action plan. London: Report to Defra. http://users.aber.ac.uk/mec/Publications/Reports/Value%20UK%20BAP%20FINAL%20published%20report%20v2.pdf

Clark, J., Gallego-Sala, A., Allott, T., & Chapman S (2010) Assessing the vulnerability of blanket peat to climate change using an ensemble of statistical bioclimatic envelope models. Clim Res 10:131–150. doi: 10.3354/cr00929

Dickie, I., Evans, C., Smyth, M-A. & Artz, R. (2015) Scoping the Natural Capital Accounts for Peatland. Report to Defra. http://sciencesearch.defra.gov.uk/Document.aspx?Document=12483_PublicationversionPeatlandAccountsscopingreportMarch2015.pdf

Dieleman, C.M., Branfireun, B.A., McLaughlin, J.W. et al. (2016) Enhanced carbon release under future climate conditions in a peatland mesocosm experiment: the role of phenolic compounds Plant Soil 400: 81. https://doi.org/10.1007/s11104-015-2713-0

ECI, HR Wallingford, Climate Resilience Ltd and Forest Research (2013) Assessing the preparedness of England's natural resources for a changing climate: exploring trends in vulnerability to climate change using indicators. Report to the ASC. https://www.theccc.org.uk/publication/assessing-preparedness-englands-natural-resources-changing-climate-exploring-trends-vulnerability-climate-change-using-indicators/

Evans C, Morrison R, Burden A, Williamson J, Baird A, Brown E, Callaghan N, Chapman P, Cumming C, Dean H, Dixon S, Dooling G, Evans J, Gauci V, Grayson R, Haddaway N, He Y, Heppell K, Holden J, Hughes S, Kaduk J, Jones D, Matthews R, Menichino N, Misselbrook T, Page S, Pan G, Peacock M, Rayment M, Ridley L, Robinson I, Rylett D, Scowen M, Stanley K, Worrall F (2016). Lowland peatland systems in England and Wales – evaluating greenhouse gas fluxes and carbon balances. Final report to Defra on Project SP1210, Centre for Ecology and Hydrology, Bangor. http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&ProjectID=17584&FromSearch=Y&Publisher=1&SearchText=sp1210&SortString=ProjectCode&SortOrder=Asc&Paging=10#Description

Evans, C., Artz, R., Moxley, J., Smyth, M-A., Taylor, E., Archer, N., Burden, A., Williamson, J., Donnelly, D., Thomson, A., Buys, G., Malcolm, H., Wilson, D., Renou-Wilson, F. (2017). Implementation of an emission inventory for UK peatlands. Report to the Department for Business, Energy and Industrial Strategy, Centre for Ecology and Hydrology, Bangor.88pp. https://uk-air.defra.gov.uk/assets/documents/reports/cat07/1904111135_UK_peatland_GHG_emissions.pdf?utm_source=IUCN+UK+Peatland+Programme+Master+List&utm_campaign=427bf1bbe5-EMAIL_CAMPAIGN_2019_04_12_09_55&utm_medium=email&utm_term=0_7872ad6518-427bf1bbe5-115211077

Fenner, N. & Freeman, C. (2011) Drought-induced carbon loss in peatlands. Nature Geoscience. 4, p895–900

Ferré, M. (2017) Sustainable Management of Cultivated Organic Soils in Switzerland – An Economic and Policy Analysis. PhD Thesis. https://www.research-collection.ethz.ch/handle/20.500.11850/213859

Frankel, B. (2018) Fictions of Sustainability: The Politics of Growth and Post-Capitalist Futures. Greenmeadows. 350pp

Gallego-Sala A, Clark J, House J, Orr H, Prentice I, Smith P, Farewell T, Chapman S (2010) Bioclimatic envelope model of climate change impacts on blanket peatland distribution in Great Britain. Clim Res 45:151–162. doi: 10.3354/cr00911

Gallego-Sala, A.V. & Prentice, I.C., (2013). Blanket peat biome endangered by climate change. Nature Climate Change 3, 152–155.

Glenk, K. & Martin-Ortega, J. (2018) The Economics of Peatland Restoration. Journal of Environmental Economics and Policy. V7, p1-18. http://www.tandfonline.com/doi/full/10.1080/21606544.2018.1434562

Glenk, K., Faccioli, M. & Martin-Ortega, J. (2018) Report on findings from a survey on public preferences for peatlands restoration: timing & long term resilience of peatlands under climate change. Report to Scottish Government. https://www.see.leeds.ac.uk/fileadmin/Documents/research/sri/peatlands/RESAS_114_Deliverable_O4.2iii_Peat_Survey_2017_summary_report_August_2017.pdf

Grand-Clement, E., Anderson, K., Smith, D., Luscombe, D., Gatis, N., Ross, M. & Brazier, R.E. (2013) Evaluating ecosystem goods and services after restoration of marginal upland peatlands in South-West England. Journal of Applied Ecology, Volume 50/2, p324–334

Graves, A. R. & Morris, J. (2013) Restoration of fen peatland under climate change. Report to the Adaptation Sub-Committee of the Committee on Climate Change. https://www.theccc.org.uk/wp-content/uploads/2013/07/Report-for-ASC-project_FINAL-9-July.pdf

Harlow J, Clarke S, Phillips M, Scott A. (2012) Valuing land-use and management changes in the Keighley & Watersheddies catchment. Peterborough: Natural England Research Report No.44. http://publications.naturalengland.org.uk/file/1312018

HMG (2018). A Green Future: Our 25 Year Plan to Improve the Environment. Published by Defra. https://www.gov.uk/government/publications/25-year-environment-plan

Li, P., Holden, J. & Irvine, B. (2016) Prediction of blanket peat erosion across Great Britain under environmental change. Climatic Change 134: 177. https://doi.org/10.1007/s10584-015-1532-x

Martin-Ortega, J., Glenk, K., & Byg, A. (2017). How to make complexity look simple? Conveying ecosystems restoration complexity for socio-economic research and public engagement. PLOS ONE, 12(7), e0181686.

Moxey, A. & Moran, D. (2014) UK Peatland Restoration: some Economic Arithmetic. Science of the Total Environment, 484, p114-120

Moxey, A. (2016) Assessing the opportunity costs associated with peatland restoration. Report to IUCN. http://www.iucn-uk-peatlandprogramme.org/resources/assessing-opportunity-costs-associated-peatland-restoration

Natural England (2010) England's peatlands: carbon storage and greenhouse gases (NE257). Report by Natural England. http://publications.naturalengland.org.uk/publication/30021

Okumah, M., Walker, C., Martin-Ortega, J., Ferré, M., Glenk, K. & Novo, P. (2019). How much does peatland restoration cost? Insights from the UK. University of Leeds - SRUC Report.

Parish, F., Sirin, A., Charman, D., Joosten, H., Minayeva, T., Silvius, M. and Stringer, L. (Eds.) 2008. Assessment on Peatlands, Biodiversity and Climate Change: Main Report. Global Environment Centre, Kuala Lumpur and Wetlands International, Wageningen.

ONS (2016) Experimental carbon stock accounts. https://www.ons.gov.uk/economy/environmentalaccounts/datasets/experimentalcarbonstockaccounts

Robroek, B., Jassey, V., Payne, R., Martí, M., Bragazza, L., Bleeker, A., Buttler, A., Caporn, S., Dise, N., Kattge, J., Zając, K., Svensson, B., van Ruijven, J. & Verhoeven, J. (2017) Taxonomic and functional turnover are decoupled in European peat bogs. Nature Communications, 8, Article number: 1161 Pettinotti, L. (2014) Economic merits of peatlands restoration in Scotland. www.teebweb.org/economic-merits-of-peatlands-restoration-in-scotland

Smyth, M.A., Taylor, E.S., Birnie, R.V., Artz, R.R.E., Dickie, I., Evans, C., Gray, A., Moxey, A., Prior, S., Littlewood, N. and Bonaventura, M. (2015) Developing Peatland Carbon Metrics and Financial Modelling to Inform the Pilot Phase UK Peatland Code. Report to Defra for Project NR0165, Crichton Carbon Centre, Dumfries.

Swindles, G., Morris, P., Baird, A., Blaauw, M. & Plunkett, G. (2012) Ecohydrological feedbacks confound peat-based climate reconstructions. Geophysical Research Letters, v39/11, https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2012GL051500

Swindles, G., Morris, P., Wheeler, J., Smith, M., Bacon, K., Turner, E., Headley, A. & Galloway, J. (2016) Resilience of peatland ecosystem services over millennial timescales: evidence from a degraded British bog. Journal of Ecology, 104/3, p621-636.

Thomson, A., Misselbrook, T., Moxley, J., Buys, G., Evans, C., Malcolm, H., Whitaker, J., McNamara, N. & Reinsch, S. (2018) Quantifying the impact of future land use scenarios to 2050 and beyond - Final Report. CEH Report to the UK Committee on Climate Change. https://www.theccc.org.uk/publication/quantifying-the-impact-of-future-land-use-scenarios-to-2050-and-beyond-centre-for-ecology-and-hydrology-and-rothamsted-research/

Wichtmann, W., Schröder, C., Joosten, H. (2016) Paludiculture – cultivation of wet peatlands. Climate protection, biodiversity, regional economic benefits, Schweizerbart Science Publishers.