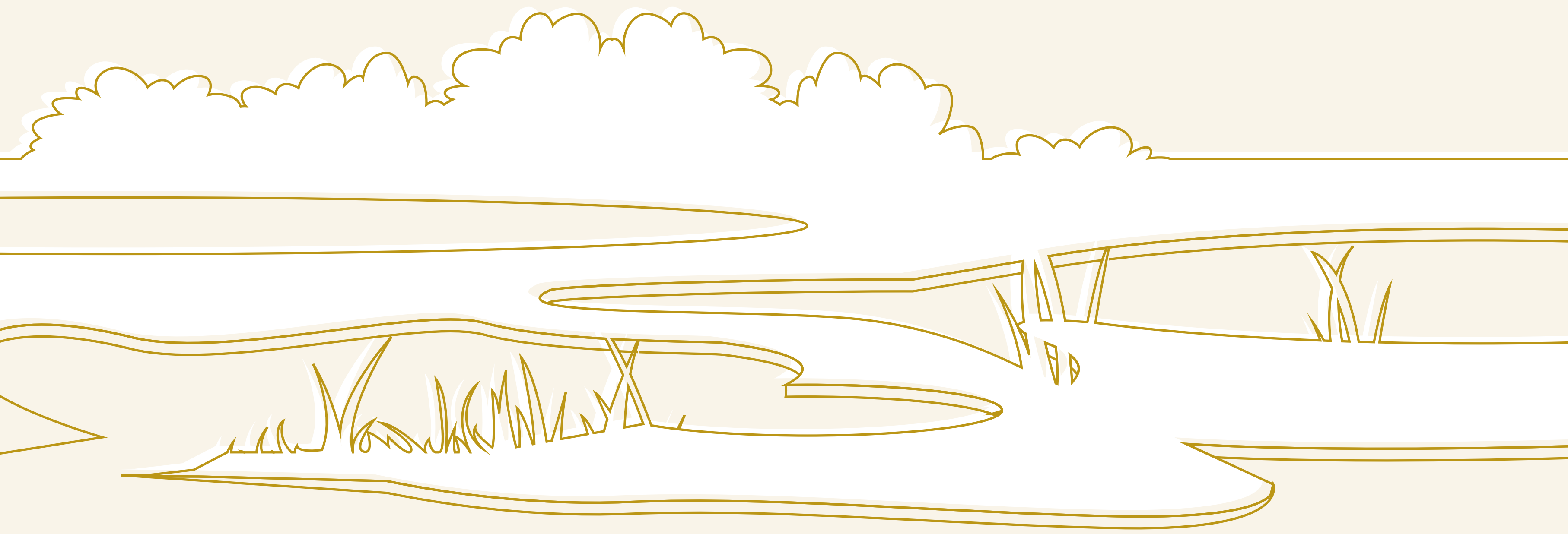
IUCN National Committee United Kingdom

Peatland Programme

Peatlands and Methane

Summary

- Methane emissions from healthy peatlands are natural. Drained peatlands emit less methane than healthy peatlands but are often a large source of carbon dioxide (CO_2). It is therefore important to consider the net balance of greenhouse gases (GHGs) over time and not to single out one GHG of concern e.g. methane (CH_4).
- Whilst rewetting drained peatlands can increase methane emissions initially, CO_2 emissions are significantly reduced, and the many other benefits of peatland restoration begin to be realised.
- When considering the overall GHG balance across UK peatlands, natural peatlands act as a sink, rewetted peatlands as a small source and degraded peatlands as a large source of GHGs. An estimated 80% of UK peatlands are in a degraded condition.
- Rewetting is the best option for reducing emissions and should be done as quickly as possible. Methane emissions from rewetted peatlands can be minimised by choosing the most suitable restoration techniques and applying appropriate management and aftercare.



Methane cycling in healthy peatlands

Source

In undisturbed peatlands, peat accumulates due to the incomplete decomposition of organic matter under waterlogged conditions. In the presence of oxygen, microbes break down organic matter and release CO_2 and water. Waterlogging causes anaerobic conditions: oxygen is not readily available, microbial populations are small, and temperatures are lower, leading to slow rates of decomposition. Methanogenesis is the form of respiration that occurs in anaerobic conditions, and CH_4 is released in the final step of anaerobic decomposition by methanogenic microorganisms.

Methane production in healthy peatlands is largely controlled by the availability and quality of substrate, but also by temperature and pH. Most methane is produced from 'young' labile carbon that has been recently fixed, and methane production decreases with depth below the water table as the amount of labile carbon is lower in deeper peat.[1,2] Old peat layers and mosses are more resistant to decomposition. Many vascular plants on the other hand provide fresh, labile substrate directly in the anoxic zone, enhancing methane production.[3] Labile carbon must be available and abundant for substantial methane production.

Seasonality

There is some seasonal variation in methane production in peatlands, as methanogenesis is a temperature-sensitive process.[4] This often leads to less substantial emissions during winter and autumn, despite the higher water table during these months.[4] Methane production is consistently low at temperatures below -5°C,[1] whereas studies have recorded increased methane production rates over the summer months from a hummock peat in an oligotrophic fen[5] and from a rewetted peatland.[4] Other studies have shown that in addition to temperature, variation in the availability of substrate and variability within the active microbial biomass in peat can explain the seasonal variation in methane production.[6]

Transport

Not all methane produced in peat will reach the atmosphere. Methane-oxidising (methanotrophic) bacteria that occupy the aerobic zone close to the water table and around plant roots consume considerable amounts of the methane produced by archaea in the water-saturated peat below. Symbiotic relationships also exist between methanotrophs and *Sphagnum* mosses growing in wet locations, and *Sphagnum* can therefore act as a 'methane filter'.[7,8]

Methanotrophs can significantly limit the amount of methane that is released to the atmosphere, because their potential to oxidise methane is usually an order of magnitude greater than the methane production potential of methanogens.[9] In wetlands, an estimated 20-40% of methane produced in anaerobic conditions is oxidised by methanotrophs.[10]

Methane can be transported from deep peat to the atmosphere in three ways: slow diffusion through the peat to the surface, ebullition of methane gas bubbles from waterlogged layers and transport through the stems of plants, called plant-

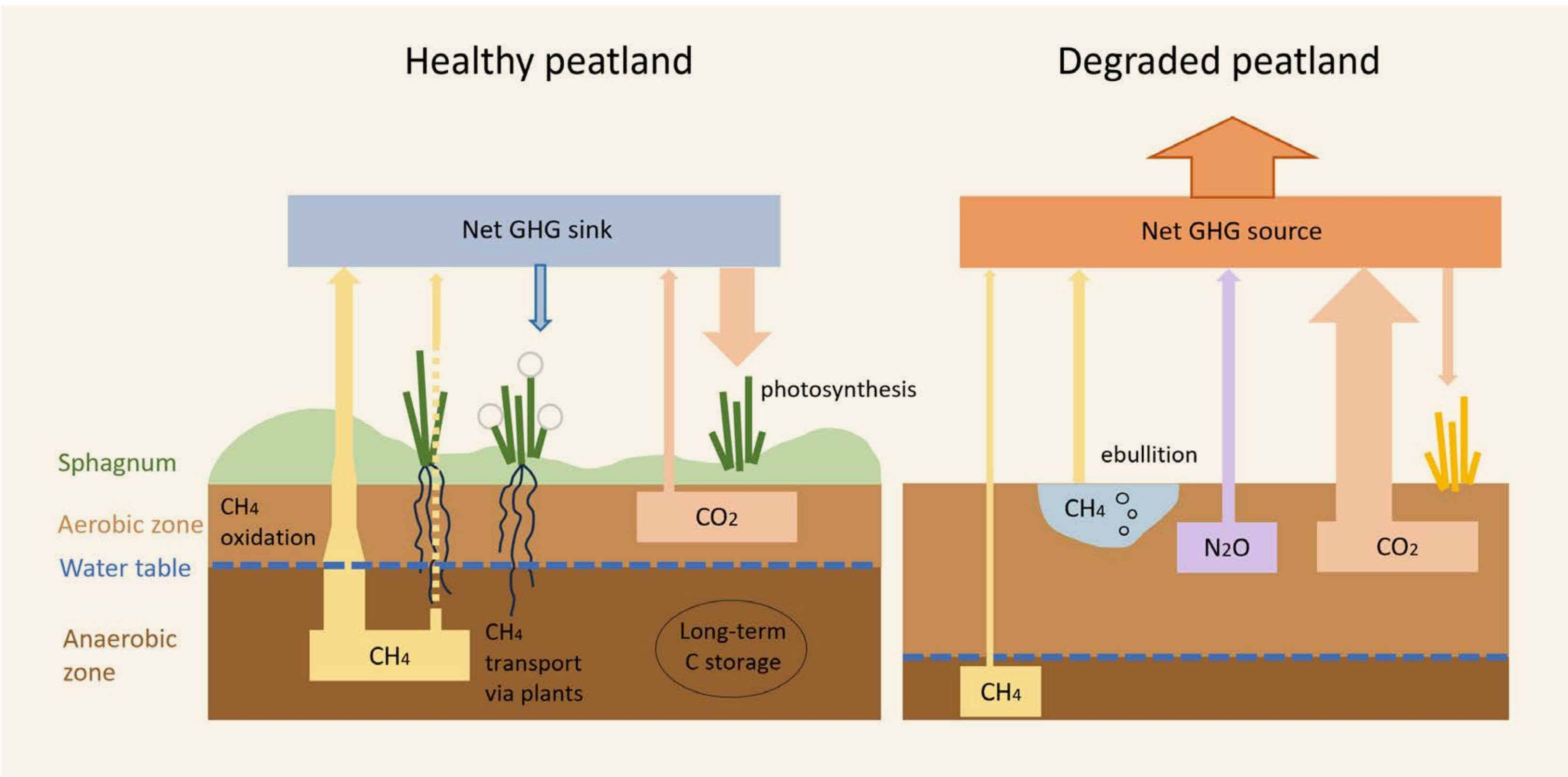


Figure 1. The greenhouse gas exchange between the different layers of peat and the atmosphere on a healthy bog peatland compared to a degraded peatland.

Cottongrasses (*Eriophorum* spp.) are aerenchymatous species belonging to the sedge family Cyperaceae. © Laurie Campbell, SNH

mediated transport. Some vascular plants, like cottongrasses (*Eriophorum* spp.) and bulrushes (*Typha* spp.), contain spongy tissue (aerenchyma) made up of large air spaces that help to transport oxygen from the atmosphere to the plant roots. The stems and leaves of these 'aerenchymatous' or 'shunt' species can act as chimneys, allowing methane to escape from the anaerobic zone directly into the atmosphere, increasing methane loss from the peatland.

Conversely, oxygen is transported to plant roots through aerenchyma, and the leakage of oxygen through roots into the anoxic peat can lead to local oxidation of methane to CO_2, leading to a reduction in methane emissions.[11] Areas of peatland dominated by sedges are associated with higher methane fluxes compared to areas with other peatland vegetation.[12] However, this carbon loss could be offset if the sedge communities themselves act as a strong sink of atmospheric CO_2.[12] More research is needed to fully understand the impact of localised vegetation communities on the carbon balance of peatlands. However, **methane release from peatlands is affected by the structure and composition of surface vegetation.**

Annual mean water levels also influence methane emissions from a peatland. Both methane producing and methane consuming microorganisms are adapted to fluctuations in water levels and remain at the same depth in peat as water levels change.[1] High water levels increase the thickness of the anaerobic zone whilst reducing the thickness of the aerobic zone, leading to increased production and reduced consumption of methane.[2] Conversely, less methane is produced, and more is consumed when the water table is low. In temperate peatlands, significant methane emissions have been observed only at mean annual water levels above -20 cm. However, when a peatland becomes flooded and water levels reach above the peat surface, methane emissions can often be lower due to methane oxidation in the oxygenated water column.[2] Water levels and the presence and absence of shunt species can therefore be used as robust indicators for methane emissions.[1]

Global warming potential

Although methane is 28 times more potent at trapping heat in the atmosphere than CO_2, its atmospheric lifetime is much shorter (~12 years) compared to CO_2 (up to hundreds of years). Methane will eventually oxidise in the atmosphere to produce water and CO_2. **As most methane emitted by peatlands is produced from recent vegetation which absorbed CO_2 from the atmosphere to grow, the CO_2 produced as the atmospheric methane decomposes does not contribute further to global warming.** Continuous methane emissions from healthy peatlands are natural and a dynamic equilibrium is eventually established as the same amount of methane disappears from the atmosphere as is added. This means that **the amount of methane released to the atmosphere by healthy peatlands remains the same in the long term, and there is no further warming impact on the climate.** Instead, over longer timescales, natural peatlands have a strong net cooling effect on the climate, as they are generally a net sink of carbon: more carbon is taken up by peatland plants through photosynthesis than is lost to the atmosphere from decomposition in the form of CO_2 and CH_4.[12,13]

Approximately 20% of the total peat area of the UK is in a near-natural condition, and it is estimated that near-natural bogs and fens in the UK act as a significant CO_2 sink of c. 1,800 kt CO_2 yr^{-1}.[13] However, when accounting for the global warming potential (GWP) of the methane emitted, these near-natural peatlands are close to carbon neutral (Figure 2), with bogs being a very small net source and fens a small sink of greenhouse gases. **Global peatlands have had a global cooling effect of about 0.6°C over the past 10,000 years.**[14]

Carbon budget of peatlands

Methane represents a small proportion (<10% in mass terms) of the total carbon budget of peatlands.[15] To estimate the overall warming or cooling effect of a peatland on climate, the overall carbon balance of the peatland must first be estimated. This carbon balance can then be converted into a measure of radiative forcing.[12] The radiative forcing effect of methane can be calculated using the IPCC global warming potential (GWP) approach. Due to the potency of methane, it is therefore possible to have a scenario where a peatland is a net sink of carbon, but also has a net positive radiative forcing (warming) effect on climate.[12]

The IPCC has set different targets for all three greenhouse gases relevant for peatlands (CH_4, CO_2 and N_2O). CO_2 should be reduced to zero by 2050, whilst CH_4 and N_2O emissions should be reduced *significantly*.[16] **Rewetting of peatlands can reduce CO2 and N2O emissions to around zero, whilst CH_4 emissions from rewetted peatlands can be limited through appropriate management practices.**

Global methane emissions from wetlands are also much lower (149-194 million t yr^{-1}) than those from agriculture and waste management (206-227 million t yr^{-1}).[17] Fossil fuel production and use emits a further 111-128 million t CH_4 yr^{-1}, highlighting that human-made sources are mainly responsible for the increase in atmospheric methane concentration.[18]

Rewetted peatland at Airds Moss. © Emma Hinchliffe

Methane emissions from degraded peatlands

Peatland degradation, particularly drying, disturbs the carbon dynamics of a peatland. Methane production in drained peatlands is lower due to the absence of anaerobic conditions. Drainage significantly reduces methane emissions from northern peatlands - on average by 84%.[19] However, methane continues to be emitted from drainage ditches, which act as hotspots in degraded agricultural peatlands.[12] In the UK, estimated methane emissions from drained peatlands range from 1.68 - 2.4 tCO_2e ha-1 yr^{-1} whilst near-natural peatlands emit 3.17 - 4.01 tCO_2e ha-1 yr^{-1}.[20]

Drained blanket peat, Marsden Moor. © Penny Anderson

Although methane emissions are lower, degraded peatlands often become an enormous overall carbon source. As the water table drops and peat becomes exposed to oxygen, previously waterlogged organic matter becomes available for aerobic decomposition. The rates of aerobic decomposition are up to orders of magnitude greater compared to anaerobic decomposition, causing large increases in CO_2 emission rates. Plant productivity may substantially decrease in degraded (e.g., cutover, drained, or eroding) peatlands, leading to reduced rates of CO_2 uptake from the atmosphere. Both consequences could turn the peatland into a carbon source.[12,21,22] If left unrestored, peatlands can remain a persistent source of carbon to the atmosphere as carbon from the peat soils is mobilised and released.[23]

Methane emissions from previously degraded, rewetted peatlands

Restoration of degraded peatlands does not always lead to lower GHG emissions in the short term. Rewetting recreates anoxic conditions in the peat, restarting methane production and increasing methane emissions by an average of 46% in northern peatlands compared to the degraded state.[19] Methane emissions from rewetted peatlands are usually similar to those from natural peatlands, although higher emissions may occur at the early stages of restoration, especially if the peatland is permanently inundated.[1,24]

Standing water and the type of vegetation can create hotspots of methane emissions from rewetted peatlands. Open water pools behind ditch blocks or bunds can be seasonal hotspots.[25] Vegetation composition in restored peatlands is often different from the pre-damage plant cover. The altered hydrology, soil properties and nutrient availability in rewetted peatlands often create an environment less suitable for peat-forming *Sphagnum* and more suited for vascular vegetation, particularly graminoids (grasses and grass-like plants).[11] Unlike *Sphagnum*, graminoid biomass provides a fresh, labile substrate for methanogenesis. Aerenchymatous graminoids can further enhance methane loss by facilitating the transport of methane to the atmosphere. High methane emissions have been observed over wet areas supporting vascular plants such as common cottongrass (*Eriophorum angustifolium*) and bogbean (*Menyanthes trifoliata*).[12]

However, the initial rise in methane emissions after rewetting decreases with time, and once typical peatland vegetation has established after 5-10 years, methane emissions are comparable to those from healthy peatlands.[1] More importantly, rewetting significantly reduces or entirely avoids CO_2 emissions in temperate peatlands, as the aerobic zone in peat is reduced and aerobic respiration repressed.[26] Whilst rewetted peatlands can have a small overall warming effect, it will be much lower compared to that of drained peatlands.[27,28]

Net ecosystem exchange must therefore be considered to fully evaluate the net effect of peatland management practices on greenhouse gas balances. Recent estimates for the UK suggest that rewetted fens and bogs currently act as a carbon sink, but methane emissions from these environments outweigh carbon uptake (Figure 2). Methane emissions depend on the nature of damage and the type of restoration.[12] However, **the average GHG emissions from rewetted peatlands are 88% lower compared to degraded peatlands** (see Fig. 2).

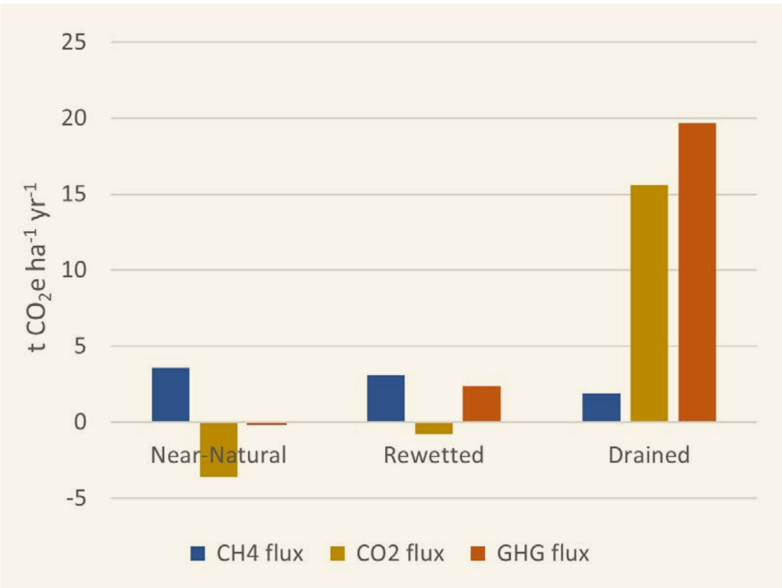


Figure 2. Average methane, carbon dioxide and overall greenhouse gas fluxes from peatlands in different conditions, based on Evans *et al.* (2022). GHG flux is a sum of CH_4, CO_2 and N_2O fluxes. Positive values indicate a source and negative values a sink of gases. Note that the GHG flux for near-natural peatlands is -0.02 $tCO_2e\ ha^{-1}\ yr^{-1}$, representing a small overall sink.

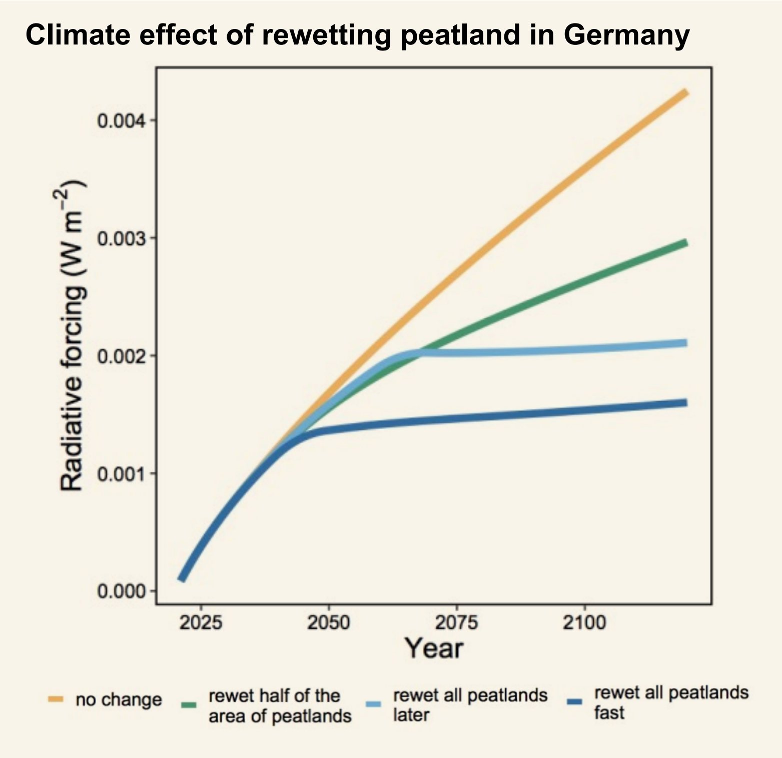


Figure 3. Climate effect of different peatland rewetting approaches in Germany. Source: Greifswald Mire Centre, 2022.

The highest overall GHG emissions come from degraded peatlands used as cropland and intensive grassland, both requiring deep drainage. The substantial CO_2 losses from degraded peatlands therefore greatly outweigh the lower average methane emissions.

Once peatlands have been drained, two options remain:

1. rewet and potentially increase methane emissions;
2. or leave peatlands in a degraded state, which results in high, continued CO2 and N2O emissions.

Although rewetted peatlands may not always be carbon sinks in the early stages after rewetting, their global warming potential is much smaller than that of drained peatlands. Rewetted peatlands also have less of an impact on global warming, particularly in the longer term.[13] **Rewetting is therefore always a better choice from a climate impact point of view, despite increased methane emissions.**

It is best to **rewet as fast as possible** (before 2040 to prevent the methane emissions from amplifying peak global warming) (Figure 3) and limit methane emissions by selecting appropriate management options.[29]

Management practices to limit methane emissions

Methane emissions from rewetted peatlands can be reduced through various management practices. As methane hotspots are related to standing water and vegetation type, practical interventions should primarily target hydrology and ground cover. The following recommendations are based on Ramsar Global Guidelines for Peatland Rewetting and Restoration (2021)[29] and the Greifswald Mire Centre (2022).[30]

Management practice	Effect
Raising water level incrementally	Raising water levels gradually helps to ensure recolonisation of nutrient-poor, acid peat by allowing tussock vegetation to grow up with the rising water level.
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Avoiding open water areas (including in ditches) and prolonged summer inundation	Blocking of drainage ditches is a common restoration practice on degraded peatlands. Methods of rewetting that do not create additional open water areas should be favoured to avoid creating hotspots of methane emissions.[12]
Rapidly re-establishing peat forming plants (mosses) and promoting typical peatland species	Methane emissions can be limited by ensuring the establishment of a mosaic of vegetation communities characteristic of peatlands. For example, *Sphagnum* mosses are peat-forming and form symbiotic relationships with methanotrophs, acting as a 'methane filter'. Whilst sedge-dominated areas of peatland are often associated with higher methane emissions, more research is needed to fully understand the overall effect of sedge communities on the overall carbon balance of peatlands.[12] Due to this uncertainty, it may be prudent to avoid creating sedge communities with high water tables when restoring a peatland.[12] Reintroduction of plant species (e.g. direct seeding or transplanting turves) can be considered when desirable species do not establish spontaneously after rewetting.
Removing fresh above ground biomass before rewetting and avoiding submerged water plants	Experiments have shown that clipping sedges to below the water table can cause the reduction or cessation of methane emissions.[31,32] Cutting for GHG management should be balanced with other impacts associated with cutting e.g., alteration of surface topography.
Reducing soil nutrient availability and below ground biomass by removing 5-10 cm of topsoil before rewetting	Restoring drained peatlands used for agricultural practices is challenging due to the high nutrient content from mineralised peat and added fertilisers and manure. Rewetting nutrient-rich peat can further increase the nutrient content by mobilising phosphorous and nitrogen. This creates a favourable environment for fast-growing wetland plants that rapidly release the nutrients again after dying. Removing 5-10 cm of topsoil and existing vegetation before rewetting reduces the nutrient and pesticide content, exposes a more porous substrate, and prevents the rapid reestablishment of fast-growing wetland species. This method is more radical and costly, and normally applied on a small scale.

Several techniques and management practices can be used to limit methane emissions from restored peatlands, and the table above is not exhaustive. However, some practices that have been linked to methane suppression (e.g., burning, limestone addition) may not be beneficial from a conservation perspective, as they may interfere with the chemical, hydrological and ecological processes that are essential to restore in a degraded peatland to realise the full benefits.

Research and evidence gaps

- Restoration results should be monitored and evaluated to inform future planning, but gaps still exist in monitoring, evaluation, and knowledge.[29] Further flux tower installation across managed and restored peatland habitats to capture data on full GHG balance would be beneficial.
- Due to the high inter-annual and spatial variability of methane emissions from rewetted peatlands, long-term research projects and extended monitoring are required. There is currently a gap regarding monitoring times after rewetting – most studies only monitor during the first year after rewetting, or another single specified year.[26]
- There are currently contrasting differences in observed patterns of methane emissions after rewetting across individual studies, which could be explained by variations in the type of vegetation cover, but more research is required to fully understand the processes acting between vegetation, peat and water.[11]
- Further research is also needed to understand the effects of drain blocking on methane emissions from blanket peat, including previously afforested blanket peat, and more drained and rewetted peatlands should be compared for increased accuracy.[12] The carbon balance of wet sedge communities needs further study to determine whether high methane emissions are offset by CO_2 uptake.

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The International Union for the Conservation of Nature (IUCN) UK Peatland Programme exists to promote peatland restoration in the UK and advocates the multiple benefits of peatlands through partnerships, strong science, sound policy and effective practice.

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