Habitats

Bogs

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Rebuilding nature

Good practice guidance for ecological restoration

CIEEM

This document is part of a series written by experts in ecological restoration from the UK and Ireland, led by members of CIEEM's Ecological Restoration Special Interest Group. The series is prefaced by ten good practice principles for ecological restoration, set out in *Rebuilding nature: Good practice guidance for ecological restoration*, and includes five Overarching Topics that apply to any ecological restoration project in the terrestrial, freshwater and marine environments of the UK and Ireland:

- **Integrating Ecosystem Services into Ecological Restoration**
- **Project Planning and Implementation**
- **Physical Environment**
- **Large Scale Nature Recovery and Restoration**
- **Monitoring**

Accompanying the five Overarching Topics are the habitat specific documents applicable to ecological restoration projects.

Habitat type

In the UK Habitats Classification (UK Hab Ltd) bogs are a subset of wetlands that are rain-fed (ombrogenous), waterlogged habitats where peat has at some time formed in the past. It includes bogs that have been cut and harvested but excludes soligenous and topogenous wetlands[1], which are included in the Fens, Marsh and Swamp section of this guidance series. Only damaged bogs that require restoration (which are the majority) are included in this guidance (**Table 1**).

Table 1 Definitions of different bog habitats in the UKHab

Bogs f1a	Subset	Key features
f1a Blanket bog		>0.3 m peat[2] (although blanket bog can occur on shallower peat)
	f1a6 Degraded blanket bog	Little *Sphagnum* due to drainage, more *Molinia*, *Eriophorum* and *Calluna*. Damage can be from any or all of: fire, drainage, peat cutting, tree planting and overgrazing, resulting in drying and erosion
f1b Lowland raised bog		Gently curved dome raised above edges. Peat can be very deep.
	f1b6 Degraded raised bog	Structure and function of peat body inactive due to damage from any or all of: fire, drainage, peat cutting, pollution, tree planting or overgrazing
	f1b7 Other degraded raised bog	Natural regeneration not possible within c.30 years due to loss of hydrological function; excludes agricultural fields on peat

Blanket bogs are Habitats Directive Annex 1 7130 and Raised bogs are Annex 1 7110 or 7120. Bogs usually occur within an ecological landscape that might merge with heathland, fen, open water, soligenous mires, woodland and grasslands of various kinds. Some of these are also Annex 1 habitats. It is important to consider bog restoration in the wider landscape context alongside associated habitats, which may also require specific restoration measures.

Figure 1

Wybunbury Moss, Cheshire, showing juxtaposition of M2a (pale yellow areas supporting white beak-sedge *Rhynchospora alba*) and M18 (purple and dark green areas supporting heather *Calluna vulgaris* and cross-leaved heath *Erica tetralix* over a *Sphagnum* carpet) bog communities.

Photo credit: Josh Styles.

Bog woodland is a distinct habitat where native trees naturally grow on intact bogs (included as w1d6 as bog woodland in the UKHab and H91DO in Annex 1 of the Habitats Directive). There is evidence that bog woodland may have been more widespread in the past. Its tree growth is slow, stunted and represents a fine balance between woody growth and bog development. This is different from areas where invasive trees have colonised degraded bogs. In bog woodlands, trees are widely spaced (in response to the waterlogged conditions), mostly comprising Scots pine *Pinus sylvestris*, downy

1 Soligenous bogs receive water from precipitation and surface water; topogenous bogs are controlled by horizontal flows of mineral soil water confined by topography.

2 Note that this latest updated depth (V.2 of UKHab) could lead to competing definitions with Annex 1 wet heath which needs to be addressed wherever necessary.

birch *Betula pubescens* or willows *Salix* spp, with abundant *Sphagnum* and pleurocarpous mosses. Bog woodland occurs mostly in Scotland, with a few examples elsewhere, including in Dorset and the New Forest (JNCC: 91D0 Bog woodland: Description and ecological characteristics). In the Republic of Ireland, this rare wet bog woodland habitat is a sub-set of woodland on peat that is dominated by birch and is considered Annex 1 habitat.

Context

The most recent figures for bogs are included in estimates of peatland cover across the UK (Evans *et al*., 2017). Of the nearly 3 million hectares of peat (which is some 12.2% of the land surface) across the UK, 640,000 ha (22% of the UK peat cover) is estimated to be in a near-natural condition supporting bog habitat, while a further 1,213,000 ha (41%) supports some kind of semi-natural bog habitat although modified by various factors such as drainage. This total of 1.853 million hectares supporting some kind of bog vegetation (of which 60% lies in Scotland) constitutes about 7.6% of the UK's land surface. The difference between the bog habitat and peat cover is a reflection of the amount of peatland habitat that has been lost. Six percent has been extracted, 7% is under cropland, 8% under grassland and 16% afforested (Evans *et al*., 2017).

Evans *et al.*'s (2017) assessment did not include the Republic of Ireland, where raised and blanket bogs cover 1.08 million hectares. Forty percent of the Republic of Ireland's peatlands have already been destroyed by peat extraction and 28% have been afforested, leaving only 248,355 ha of bogs of conservation value, 22.9% of its original bog habitat (Irish Peatland Conservation Council - Extent & Utilisation of Irish Peatlands).

All the totals are approximate due to differing and changing definitions of deep peat and in the resolution and methodologies of the surveys.

Importance

Bogs are vital for numerous reasons as summarised below (IUCN Peatland Programme: Peatland Benefits, Renou-Wilson *et al*., 2018; Thom *et al*., 2019).

1. Biodiversity

a. Bogs include the largest area of semi-natural habitat remaining in the UK and Ireland and, as they are globally rare, this is internationally important;

b. Bogs host nationally and internationally important species that are often specialists adapted to these nutrient-poor, wet, acidic habitats. Selected *Sphagnum* species are the keystone group, sharing space with various sedges, brown mosses and other typical plants. They provide habitat for a specialist fauna, including important bird assemblages, with an exceptionally high proportion of species with legal protection under UK and European conservation law (Bain, 2021; IUCN Peatland Programme).

c. Blanket and raised bogs are priority habitats; however, only around 20% or less of blanket bogs in the UK and Ireland remain undamaged, and just 1% of lowland raised bogs are intact. As a result, the remaining less-damaged bogs are of particularly high conservation value, and there is increased urgency to restore those that have been degraded.

d. Many of the typical bog species are exhibiting marked population declines which will increase their rarity and therefore their importance.

Figure 2

Good quality patch of blanket bog within a cutover site, Northern Ireland. A cutover is 'any bog site cut by hand or mechanical means and where there is still an economic reserve of peat remaining' (definition from https://www.ipcc.ie/a-to-z-peatlands/peatland-glossary/).

Photo credit: Penny Anderson.

2. Ecosystem Services

a. Carbon store: peatlands (most of which will be bogs) are the single most important terrestrial carbon store anywhere, locking up an estimated 3.2 billion tonnes carbon in the UK alone[3] (compared with about 4.1 billion tonnes of CO_2 equivalent (about 1.1 billion tonnes of carbon) in UK forests[4]). They do not, however, sequestrate carbon significantly or rapidly. Evans *et al*. (2017) estimate that near-natural bogs act as a significant CO_2 sink, but this is counterbalanced by methane emissions, resulting in near-natural bogs being approximately carbon neutral in terms of carbon sequestration.

b. Damaged bogs are losing more carbon than they can sequestrate. Damage caused by drainage, afforestation, acid rain, peat harvesting or severe burning (wildfire mostly) results, directly or indirectly, in loss of this carbon store. This is extreme in reclaimed agricultural peatlands (largely former raised bogs), but also severe for eroding, bare blanket bog (Anderson, 2024) (see Overarching Topic – Integrating Ecosystem Services into Ecological Restoration). The combined losses are greater than the amount sequestrated by all other habitats (UK Parliament Research Briefing: Reducing Peatland Emissions 20 April 2022) at 23,100 kt $CO_2e\ yr^{-1}$ (Evans *et al*., 2017).

Figure 3

Blanket bog damaged through wildfire, past air pollution and gully erosion, South Pennines.

Photo credit: Penny Anderson.

c. Historic value: intact peat under bogs is an environmental archive (through analysis of pollen, plant and animal remains) of conditions during its development for up to 10,000 years, and also preserves other archaeological remains. Some bogs were ancient cultural places such as those used by Iron Age people for votive offerings

3 UK Centre for Ecology and Hydrology Peatlands Factsheet

4 Forest Research: Forestry Statistics 2025, Chapter 4 - Carbon

and possible human sacrifice (Lindow Man, Cheshire is one example). The historic value contributes not only to knowledge of our history but also to climate change – a record that is easily lost or damaged.

d. In the UK, some 70% of our drinking water is derived from surface water running off upland catchments that are mostly peat-covered. Runoff from damaged peat requires more costly treatment to remove Dissolved Organic Carbon (DOC) (Martin-Ortega *et al*., 2014; IUCN Peatland Programme: Peatland Benefits/Water Quality)

e. Fairly intact peat bogs are relatively flashy[5] as the living surface (the acrotelm) is quite shallow and has a low storage capacity. However, severely damaged peat, especially in blanket mires, can contribute to even more rapid runoff and heightened downstream flooding. Restored blanket peats can significantly reduce downstream flood peaks and flows (Pilkington *et al.,* 2015).

f. The cultural value of bogs is high. They are national treasures, providing a sense of place and open landscapes highly valued for access and amenity. They are important for our health and wellbeing as well as an educational resource.

g. They are highly valued by managers for game and / or stock grazing.

Large areas of peatland are also included in nationally and internationally designated sites for nature conservation, and many of these are in poor condition in terms of their functionality and composition. Damaged peatlands are a cost to society through increased greenhouse gas (GHG) emissions and loss of other ecosystem services. Peatland restoration is a cost-effective solution in mitigating climate change; with the UK and Republic of Ireland having world-leading expertise in restoration, there is an imperative to restore these habitats wherever possible. This will benefit nature conservation, climate change resilience and other diverse and important ecosystem services.

The separate UK countries have developed peatland strategies, downloadable from the IUCN peatland programme website IUCN Peatland Programme: UK Strategy). The Republic of Ireland now has new bog objectives and actions in its Irish Government National Climate Action Plan 2024 and 4th National Biodiversity Action Plan 2023-2030.

Intervention Measures

For this guidance, restoration has been defined as incorporating habitat creation, restoration and translocation[6]. However, restoration is currently the only viable option for repairing degraded bogs. Bog creation is unrealistic as bogs are ancient habitats where peat accumulated for 4,000 to 10,000 years under very specific environmental conditions. There is no evidence for the efficacy of translocating bogs in achieving a functioning habitat, so it is not recommended. Some guidance on dealing with peat in development projects, such as renewable energy schemes, has been included here as there are high risks of carbon being lost with any excavation of peat. However, this is not considered as restoration of bog habitat.

Restoration focuses critically on working towards 'active' bog condition (as defined under Annex 1 of the Habitats Directive), which mostly entails reinstatement of near-natural water tables and other conditions to support vegetation that is normally peat-forming.

Selecting the most appropriate measures depends on assessing the situation, all the factors that influence it, and then applying the interventions. There is excellent guidance available on all these steps:

5 Flashy = rapid discharge during rain events and rapid return to base conditions.

6 CIEEM: Rebuilding Nature - Good Practice Guidance for Ecological Restoration Jan 2024

- Several documents are on the IUCN Peatland Programme website, including the Yorkshire Peat Partnership's comprehensive guidance for all types of project: *Conserving Bogs: the Management Handbook* (Thom *et al.*, 2019); the Peatland Action Technical Compendium for peatland restoration in Scotland; and details of a new EA-supported project to develop Eco-hydrological Guidelines for Blanket Bog.
- NatureScot Peatland ACTION: Project Resources includes videos and written guidance designed for all involved, (including contractors).
- For Ireland, best practice guidance and much useful information can be found in Mackin *et al*. (2017) and on the Irish Peatland Conservation Council website.
- More information and reports on trials and on many of the available measures are available from the Moors for the Future Partnership/Resources (one of the first major peatland restoration programmes).

Site Assessment

Peat condition, site constraints and opportunities need to be assessed as a first step. Peat condition has developed from various damaging factors, whilst the constraints or opportunities determine how and when works can be conducted. At the same time, it is essential to investigate the processes, measures and outcomes of any similar work nearby or in similar habitats. Refer to the IUCN Peatland Code Field Protocol for overall peatland condition categories.

The following explains peat condition and site constraints and opportunities assessments in more detail.

1. Peat condition:

a. Rewetting requires an understanding of local water tables combined with the broader hydrological processes of the site.

b. Reinstating the water table to near natural levels where possible through a variety of damming methods will be key to successful restoration. Dipwells should be used to measure water tables pre-restoration, ideally for a year. Measure DOC in outflows too, if there are water quality concerns downstream.

c. For the wider hydrological catchment units, an understanding of water movement, hydrological unit boundaries and water preferential pathways is needed. Map the streams, drains, gullies and grips (man-made drains). Are the grips separate from, or do they feed into the gullies/streams? Are there peat pipes[7]? Try to assess their abundance, which is likely to be higher where repeated wildfires or gripping have affected blanket bogs. Peat pipes can divert water flow and reduce dam efficacy.

Figure 4

Gripped blanket bog in Southern Uplands, Scotland; parallel man-made drains are clearly visible.

Photo credit: Mike Perkins

7 A peat pipe is an underground channel or tunnel within the peat through which water flows.

d. Determine the pattern of flow in the drainage system e.g. in a damaged raised bog. This indicates flow rates in storm conditions and therefore the type of dams and their locations.

e. Assess any flushes, marginal fen, drainage and underground flows which might have been channelised to help build a picture of water flows, mostly in damaged raised bogs.

f. Many of these hydrological investigations can be conducted in an eco-hydrological modelling exercise, working closely with suitably experienced hydrologists. Such modelling and any action plan should seek to avoid flooding peat and raising water tables to such an extent that methane becomes a major product, adding much more to GHGs (see Overarching Topics – Integrating Ecosystem Services into Ecological Restoration).

g. Assess the site in its wider hydrological setting to consider adjacent habitats and land uses. Re-wetting may need to avoid impacting the hydrology of adjacent properties or priority habitats. In the Republic of Ireland, drainage management plans are prepared for raised bog restoration programmes to avoid impacting the hydrology of adjacent farmland. Several projects are engaging with adjacent land-managers who wish to support neighbouring bog restoration by re-wetting their land, which is frequently modified bog or organic-rich soil.

h. Map the depth, width and nature of the material in the bottom of the drains, grips and gullies. Are gully sides too steep to revegetate? Is reprofiling necessary – where and how much? This information determines the type of dams that can be inserted.

i. Peat depth: is it even, naturally variable, or derived from peat cutting or erosion? Dry peat shrinks, so it may be much shallower than it once was. Map peat depths using an appropriate grid for the site reflecting the level of damage.

Figure 5

Uneven bog surface due to peat cutting, Northern Ireland.

Photo credit: Penny Anderson

j. Bog vegetation: survey and identify what it tells you in terms of damage (which may be current or historic). How abundant are peat-forming species like *Sphagnum papillosum*, *S. magellanicum* group. and *S. rubellum*? How abundant are dry-ground species like heather? Plant composition can be an important indicator to understand whether the condition is stable, improving or declining. Undertaking habitat condition surveys (as produced by the Joint Nature Conservancy Council or the Country Agencies) can assist in this assessment. Additionally, are there signs of disease or pest damage such as *Phytophthora* or heather beetle *Lochmaea suturalis* to take into account?

k. Nutrient availability and acidity: is the peat damaged by burning or air pollution which might affect plant growth? Is the pH suitable for growth? High sulphur dioxide levels up to the 1980s have left very acidic peat as a legacy in the South Pennines and South Wales, for example. Nitrogen deposition is still an issue in some areas. Nutrients released from drying peat via peat mineralisation may also lead to the development of unfavourable / atypical vegetation on bogs.

l. Are breeding or wintering birds or other animal populations (e.g. some invertebrates) important. Have numbers been declining? Is this due to poor peat condition?

m. What are the levels of wild herbivores, what effect are they having and is any control or exclusion needed?

n. What is the history of management in terms of stock grazing? Is this a factor in the damage and is it current or past? Does it need to be altered / managed?

o. Investigate the past and recent history of the site in terms of wildfires, any damaging managed burning, peat extraction or other activity (e.g. off-roading, developments like tracks, military use past or present etc). Have these impacted peat condition?

p. Is there any forestry planting on peat to be removed? How was the ground treated prior to planting? Are drains and plough lines, for example, still present and functioning? Is the peat cracked in places, providing water conduits? Consider existing and neighbouring forestry plantations which may act as a seed source onto open bog. Degraded bogs are more susceptible to tree establishment that can further degrade the habitat and add ongoing management costs.

q. Peat extraction, erosion and loss: where is it, how much has been lost and what is its extent?

r. It is essential to assess the risk of peat slides from re-wetting (Scottish Government, 2017; NatureScot Report 1259: A risk-based approach to peatland restoration and peat instability).

2. Site constraints and opportunities

These are mostly determined by site users or values (see Overarching Topic – Project Planning and Implementation):

a. Are there archaeological features to avoid / protect? Remember the peat profile is an important environmental record if not too damaged.

b. Are there protected species and breeding birds? Are the site or the neighbouring land protected sites? There may be seasonal or other constraints and application of the Habitats Regulations to consider, plus consents to obtain.

c. Is game shooting / tracking part of the site's use? What needs to be considered to avoid conflict with this? How can you engage with those involved to work together effectively?

d. Are there any services crossing the site – overhead or underground?

e. What is the agricultural use – is it common land or not? Work closely with the farmers / landowners to achieve the best results for all.

f. Are there other rights of use to consider such as turbary[8] rights? There might be multiple land ownerships. One solution adopted by the state authorities in the Republic of Ireland is to negotiate with landowners and rights holders to stop cutting turf in order to support bog conservation and restoration projects; this is supported via various compensation schemes and Community Engagement Schemes (see National Parks and Wildlife Service: Peatlands and turf cutting).

g. Engage with neighbouring land managers / owners to avoid any conflicts of interest.

h. Is the site an important water catchment? Peat erosion or loss of sediment during works could be important. Consult with the local water provider.

i. Is the site open access and widely or little used for recreation? What are the opportunities for engaging with local communities / site users so they support the works and can provide voluntary input?

8 Turbary is the ancient right to cut turf, or peat, for fuel on a particular area of bog in Ireland. The turbary right would be registered on the title of land when it was registered in the Land Registry.

j. Risk assessments are needed for health and safety in a potentially hazardous environment.

k. Assess the most appropriate access routes for vehicles / helicopters and people to reach the site and implement the works.

l. Consider biosecurity measures if relevant.

Figure 6

Suitable access is needed for low ground pressure vehicles to work on blanket bog.

Photo credit: Penny Anderson.

m. Do you need any permits, authorisations or other permissions e.g. felling licence, agri-environment agreement amendments etc.?

Site assessments involve on-the-ground surveys (registered in GPS mappers) and aerial surveys. Unmanned Aerial Vehicles (UAVs) can cover ground quickly with accurate sensors to identify how water is moving across a landscape and where interventions would be most successful (see Thom *et al.*, 2019). It is important to assess the overall level of damage and to determine how much is historic and how much is continuing. This will indicate the factors that will need to be managed as part of the restoration works.

On the basis of the assessments, realistic objectives for the restoration programme in terms of targets, time scales and actions can be set. These need to reflect any relevant policy and legislation, and work to any funding requirements or constraints. From these, an action plan or plans can be formulated and costed, from which work programmes are developed, along with a monitoring and review process. This last part is an essential means of evaluating successes and failures and is vital for the site manager to be able to refine measures or undertake remedial actions. Good management planning is really a cyclical continuum allowing the programme to be reviewed and updated on a regular basis so that it remains up-to-date and relevant (see also Overarching Principles - Project Planning and Implementation).

General Principles

There are a number of general actions that apply to most situations, whilst other measures are more closely linked to specific scenarios. The following sets out a list of possible actions to follow, divided into hydrological and other guidance. Refer to the case studies section below and the guidance sources listed above for further detail and advice.

Hydrological rewetting

1. Dams

Most damage has been to the hydrology of bogs resulting in lowered water tables, sometimes drawn down over a metre, and often with prolonged draw-down periods and highly fluctuating levels. Water tables ideally should be about 10 cm below the surface on average, to wet the surface and minimise methane production. Dams are the main tool in achieving this and different materials are used depending on:

- gully or drain size and depth
- the nature of the material below the peat
- peat depth
- the gully catchment area, its runoff characteristics and likely water flows.

Dams may need to be strengthened using more than one material. Any access constraints may also determine dam type and working arrangements. The most appropriate types will need to be researched for your needs.

Dams can be made of:

- peat dug *in situ* used for low flow catchments and shallow gullies or grips. Such dams need carefully placed overflow systems to avoid erosion;
- wood as logs or planks – beware of the effects of wildfire on these and the need for an overflow mechanism. They can be stronger than plastic dams and are generally used for gullies on peat <2 m wide and < 1.5 m deep;
- tightly packed heather brash bales (again only for low flow and shallow gullies or grips <1 m wide, <50 cm deep and surfaces with <5° slope);

Figure 7

Multiple plastic dams successfully raising water levels on dried blanket bog in the Central Pennines.

Photo credit: Penny Anderson.

- recycled plastic dams withstand higher flows, can be strengthened with supports and should be watertight, thus needing an overflow mechanism. They cannot be used on mineral material or shallow peat (as half of the piling needs to be within the peat) and must be keyed into the edges by at least 30 cm. They are usually applied on gullies <2 m wide and <1.5 m deep;
- metal sheets, acting similarly to plastic sheets;
- sluices with overflow systems (also used to monitor water levels) that are usually more relevant to raised bogs;
- stone dropped by helicopter usually to create low dams in eroding gullies to catch sediment;
- composite dams for more exacting locations.

Figure 8

Failure of a composite dam not strong enough for the level of flow, Central Pennines.

Photo credit: Penny Anderson.

In some cases, dams cannot be established in the first round of works to the desired height (e.g. stone dams in deep gullies), so will not raise the water table sufficiently. Further damming will be needed, possibly over many years, to achieve the required level of rewetting.

Peat dams and then other natural materials are the preferred material but are not always appropriate where flows are higher. Distances between dams are determined by slope and flows. They are inserted at roughly 7-12 m intervals on blanket bogs, ensuring water is retained throughout each dammed sub-section. This is roughly at a 1 per 10 cm fall as also used on raised bogs (see Thom *et al*., 2019 for detailed guidance).

If mini borrow-pits are required for peat dams, it is important to consider their spacing and the need to avoid forming a string of excavation hollows that could initiate further gullying in a storm event (Thom *et al.,* 2019).

Figure 9

Volunteers installing wooden dams on blanket bog, South Pennines.

Photo credit: Penny Anderson.

2. Bunds

Bunds are impermeable barriers that may be needed to restrict water loss, as in seepages around bog edges, on slopes, or where peat has been extracted, or to impound water on the surface. Care with any impacts on adjacent land is important. Bunding, in some situations, may not result in optimal water levels, being either too low or too high for the re-establishment of active, peat-forming vegetation. *Sphagnum papillosum* is a keystone peat-forming species which is most often abundant across active raised and blanket mires. It grows best when situated 5-15 cm from the water table and does not tolerate long periods of submersion or excessive drought (Hayward & Clymo, 2012). Water levels within these parameters should be the objective of bunding wherever possible. Dipwell monitoring is fundamentally important to measure the effectiveness of this.

Peat may be suitable for forming bunds, or impermeable material may be needed depending on the bunds' dimensions and function. Peat bunds are being used to restore depleted raised bog surfaces, either as large shallow pools or as smaller units; on dry blanket bogs, small crescent-shaped bunds are being used in waves across surfaces to hold water for longer (see Moors for the Future MoorLIFE 2020: bunds trial). In the Republic of Ireland, Bord na Móna methodology includes information on bunding where peat bogs are being restored (see Methodology Paper for the Enhanced Decommissioning, Rehabilitation and Restoration on Bord na Móna Peatlands – Preliminary Study Version 19, 2022).

Figure 10

Shallow bunds to raise water tables on Solway Moss, Cumbria.

Photo credit: Penny Anderson.

Coir rolls, which are flexible (but expensive), or heather bales built into a wall can be carried to a site. Trials of felted wool rolls stuffed with sheep's wool are showing promise. Bales and rolls have been used as small-scale bunds to block peat movement and water flows on fairly flat, damaged (for example burnt) peat surfaces where an uneven surface is in danger of eroding. Plug plants (*Sphagnum* or common cottongrass *Eriophorum angustifolium* for example) can supplement the bunding to accelerate vegetation recovery.

Figure 11

Installing coir rolls on burnt blanket bog to contain water movement.

Photo credit: Penny Anderson.

3. Ditch infilling

Ditch infilling may be needed where dammed ditches are still leaking water. The material used should be nutrient-poor and relatively impermeable, meaning that dry, oxidised peat is unsuitable. Grips have been infilled in the past with mini-heather bales. These could still leak water but provide a frame for *Sphagnum* growth. Wet peat is the best material if available. This might be possible in some development projects where peat (not bog) is being moved due to, for example, wind turbine infrastructure. However, the success of this has not been proven.

Revegetation

In order to revegetate successfully it is necessary to identify the reasons for the lack of vegetation and manage the factors controlling it. These could relate to past air pollution effects on the peat, especially close to urban areas where acute acidity may prevent successful plant growth, or to erosion, frost heave and water flows which need to be stabilised first. Historic wildfire, military use and training or current off-roading can be issues. Access for materials and the workforce needs to be planned.

Exposed bare peat on blanket bogs, especially on steep slopes, can be very unstable owing to exposure and erosion from freeze-thaw cycles and runoff. Removing stock grazing is usually a first consideration, but wild herbivores (deer, rabbits or hares) may also be an issue.

Decisions need to be made on the need for:

- any added lime or fertiliser amendments depending on the pH and fertility levels in the peat. This is not always needed, and not recommended on most sites where pH and nutrient amendments could be damaging;
- any stabilisation of peat, for example by using geojute, heather brash or other materials to protect the surface and ameliorate temperature and humidity extremes as well as frost heaving;
- seed or plant introductions or reliance on natural regeneration; how close is the desired plant community and / or is there a residual viable seed bank? (samples could be cultivated in seed trays or translocated from large populations nearby). Identify any missing species that might need to be added to supplement natural colonisation; compare site species lists and floristic tables with appropriate communities as described in Rodwell (1998) or the National Biodiversity Data Centre: Irish Vegetation Classification, for example '*M18 Erica tetralix - Sphagnum papillosum* raised and blanket mire' (UK M18 or Ireland BG2);
- use plant sources as close as possible to your site;
- measures to stabilise any steeper peat slopes before revegetation, such as re-profiling steep bare peat banks or gully overhangs;
- a nurse cover of grasses; again, not often needed, but should be of non-persistent and non-invasive species.

Figure 12

Sphagnum plug established during restoration of blanket bog.

Photo credit: Penny Anderson.

The main materials used to stabilise and protect bare peat to enable revegetation are geojute and heather brash. The jute mesh size is about 25 mm square and the weight of the mesh increases about 300 % once wet, holding down the peat physically whilst providing colonisation gaps. Heather brash can be cut when the seeds are viable and still in the capsules from October to December for a source of heather seed (not usually required on deep peat), or at other times to provide a protective cover. This is less resilient than geojute but can also introduce native mosses which help protect the surface. Geojute is expensive and needs to be reserved for more difficult locations.

Adding plug plants can help diversify the habitat and a large volunteer workforce is invaluable in implementing this. *Sphagnum* plugs are most often used (but other methods and species have been trialled). Best practice would be to use locally native species - *S. papillosum* and *S. magellanicum* group are fundamentally important in reducing available nitrogen and restoring long-term hydrological functionality, and are typical of bog habitats. Specialist growers will propagate large numbers to order using local provenance material. *Sphagnum* of the appropriate species can also be harvested as handfuls where there is plenty and inserted on the restoration site provided the correct permissions have been obtained.

Figure 13

White beak-sedge has been successfully planted into several restored raised bogs in Lancashire and Shropshire.

Photo credit: Josh Styles.

Managing trees and scrub

Bogs might have been planted with conifer plantations or trees / shrubs might have colonised as habitats dry out or when grazing animals are removed for restoration works.

1. Removal of forestry

Afforestation of bogs not only replaces the former bog vegetation but also results in lowered water tables and loss of carbon as the peat is drained to aid tree establishment. The growing tree crop:

- adds to the drying effect resulting in oxidised and decomposing peat;
- produces a loss of open ground birds;
- reduces water quality through acidification and increased levels of DOC that in turn can affect fish spawning and invertebrate life downstream; and
- can result in flash flooding downstream from drainage and ploughing when on a sufficient scale (Anderson *et al*., 2000; Ramchunder *et al*., 2012; Campbell *et al*., 2019; Mackin *et al*., 2019).

Nutrient release, particularly of nitrates, after conifer removal from peatland is frequently a key factor following the degradation of peat on ombrogenous sites, which can also affect downstream water quality. Where restoration sites are in a water quality sensitive catchment, felling methods should consider whole-tree harvesting and brash recovery.

Some keystone peat-forming *Sphagnum*, especially *S. papillosum* and the *S. magellanicum* group, can readily take up nitrates, provided they are not shaded out by more vigorously growing grasses like purple moor-grass *Molinia caerulea* and there is sufficient phosphorus and potassium (Temmink *et al.,* 2017). Rapidly increasing the cover of these mosses is therefore important.

Figure 14

Block failure of peat from blanket bog into a salmonid stream, resulting partly from rapid runoff from adjacent deep forestry drains; Sperrins, Northern Ireland. High DOC levels (deep brown colour) in the river water are visible.

Photo credit: Penny Anderson.

Restoration of afforested peatlands seeks to restore the water table and the bog communities, but it requires some different approaches and actions due to the tree cover. The Forestry Commission trialled removing planted trees and restoring the peat on former blanket bog (Anderson, 2010) and, to date, 10,000 ha of blanket bog has been restored from afforestation by Forestry and Land Scotland with much more by the RSPB in the Flow Country, all in Scotland. There is considerable experience in The Republic of Ireland too, where approximately 500 ha of plantation was removed in one LIFE-funded project (Large scale restoration of blanket bog from afforestation with LIFE funding support by Coillte Teoranta in Ireland). There is also a renewed emphasis on Forest to Bog restoration on blanket bog in the Republic of Ireland, where planning permission from the local authority as well as a felling licence from the Forest Service are required for sites >50 ha owing to concerns about water quality in sensitive catchments and the risk of peat slippage.

The IUCN Peatland Programme has published comprehensive assessments of restoration from a forested cover that also includes numerous case studies demonstrating different techniques (Campbell *et al.,* 2019).

Figure 15

Drains lowering the water table in afforested blanket peat.

Photo credit: Penny Anderson.

Specific issues to consider are:

- The extent and severity of drainage, ploughing, ridge and furrow formation or peat flipping[9] for tree planting, and the ease of restoring the surface;
- The age and number of cycles of the plantation cycle since first planting. More than one cycle can result in peat cracking and roots can form new water conduits affecting the efficacy of drain / furrow blocking. The weight of larger, older trees can also compress the underlying peat;
- How much bog vegetation remains on the site;
- Past fertilisation of the crop, e.g. with phosphate fertilisers, which might result in increased growth of purple moor-grass at the expense of more diverse peatland vegetation (as experienced in the Republic of Ireland);
- Younger trees are easier to cut and windrow, often left on site, especially if they have failed in wet conditions;
- How to treat larger brash and timber – remove from site, fell to waste, use as brash mats, or chip cut material. Brash / chippings can be windrowed and left on site covering the least area, or removed, or the whole tree can be removed;
- Possible increases in DOC and sediment to streams during the restoration works as conifer leaf litter breaks down and ground surfaces are disturbed. These may be temporary. Consider any benefits of phased restoration to reduce water quality risks;
- Whether to remove the stumps and root plates or not, bearing in mind the level of disturbance removal would cause. It is standard to flip stumps into furrows from the ridges rather than removing them;

9 Peat flipping is where a block of vegetation is upturned on top of the bog surface on top of which a tree is planted. This is instead of a continuous ridge from ploughing.

- How to extract the timber and get other resources onto the site in terms of access over peat, especially if this crosses undamaged bog. Use of brash mats / floating roads / bog mats (expensive) etc may be needed. Minimising any impacts on intact bog is paramount;
- Management of herbivores – stock or deer especially.

Figure 16

Planted trees failed in wet peatland conditions, mid Wales.

Photo credit: Penny Anderson.

It can take 7-15 years or much longer for bog restoration from afforestation depending on the degree of hydrological damage (personal experience of the authors). On more isolated sites, it might not be possible to achieve a typical semi-natural community without plant species translocations of especially poor dispersers.

Restoration methods include the following:

- Various smoothing techniques to remove the uneven surface (Short & Robson, 2016) which have been shown to be effective at removing the ridge and furrow effect of ploughing (Campbell *et al*., 2019; NatureScot Peatland Action: Technical Compendium);
- Furrow and drain blocking;
- Management of surface runoff;
- Removal of any newly established conifers to the restored surface – these can be dense but can also vary greatly between sites.

2. Clearing naturally colonised trees and shrubs

Depending on the herbivore levels, drying and disturbed peat can support variable densities of trees and shrubs, in particular birch, some willows, various conifers and *Rhododendron* if there are nearby sources.

It is not clear if trees and shrubs are natural on our peatlands as they are in parts of Scandinavia and elsewhere. Richard Lindsay (international peatland expert, University of East London, pers. comm.) considers scrub and woodland to be a natural edge habitat to blanket peat, inhibiting the erosion on plateau edges that is so often visible. In some projects, where restoration is ongoing and stock excluded, there is considerable tree / shrub colonisation, such as on Dovestones (North Peak District). None is yet of any significant height, it tends to be shallowly rooted, does not seem to be affecting the ground nesting birds and may be increasing diversity of plant and bird life. It is not clear whether this will have to be controlled in the future, possibly by grazing, or whether it will be affected by regular wildfires in this urban fringe site. The scale of invasion prevents mechanical control. These kinds of situations will need careful consideration.

Figure 17

Birch colonisation after stock exclusion on Peak District blanket bog with abundant common cottongrass and heather.

Photo credit: Penny Anderson.

In addition, the native range of Scots pine may extend beyond Scotland and the Burren in the UK and Ireland respectively and may exist on some bogs as a rare and endangered truly native plant. Genetic research from sites across the UK and Ireland is currently being undertaken to better understand this species' native distribution.

In *Conserving bogs: The management handbook*, Thom *et al.* (2019) cover all aspects of how to control secondary tree and scrub invasion. Without understanding why there is scrub / tree invasion, clearance will result in further colonisation. If the causes cannot be controlled (such as colonisation from plantations etc. beyond your site), then plans to maintain control are needed so that peat surfaces are not dried out further. Restoring the water table should help reduce such growth over time.

In contrast, non-native species like invading non-native conifers or *Rhododendron* need removal on principle. Conifers do not coppice so can simply be cut down. *Rhododendron* can be pulled up when young, so is best treated early in its colonisation. It is much more difficult and costly once the plants are too big to pull. Volunteer input is beneficial for manual control. In Ireland some local community groups and local employment schemes have been trained to tackle *Rhododendron* infestation on blanket bog.

Restoration of raised bogs reclaimed earlier for agriculture

Research into the potential for this is ongoing. Paludiculture is being explored, whereby water tables are raised for new wetland crops to be grown on peat soils. This still maintains an agricultural use but reduces the shrinkage and loss of carbon from drained peat, although not restoring any kind of bog habitat. One option is to grow *Sphagnum* at scale. Temmink *et al*. (2017) showed that growing *S. palustre* and *S. papillosum* on rewetted agricultural peatland was very successful provided the pH was maintained at around 4.2, despite high levels of nitrogen deposition and a legacy of high phosphorus and potassium in the irrigation water. Other options include farming common reed *Phragmites australis*, bulrush *Typha*, or other water-loving species, all of which provide some sort of habitat whilst not resembling the original bog.

Restoring such agricultural land back to some form of raised bog is even more in its infancy and experience and research are limited. It is important first to understand the peat condition on any site where restoration could be attempted. Additional to the guidance set out above, a nutrient and pH profile, a peat depth survey, together with an understanding of any drainage that has been established is needed. The Lancashire Wildlife Trust and Natural England in Shropshire have been experimenting with topsoil stripping to remove nutrient and lime-enriched topsoil (with its potential non-bog seedbank). Combined with water table raising and management, bunding to manage surface drainage and introduction of key species, some success in moving towards a raised bog habitat has been achieved (Styles *et al.,* 2022).

In addition to soil stripping, soil inversion whereby the surface modified peat is buried below unmodified peat, is being trialled in Greater Manchester with promising early results, including the colonisation by plants typical of higher quality raised mire habitats, such as bulbous rush *Juncus bulbosus*.

In circumstances where soil stripping or inversion are unviable on agriculturally modified sites, such as where peat has been enriched and / or limed, key peat-formers are unlikely to recolonise, including *Sphagnum* or peat-forming brown mosses. In these situations, bunding or other hydrological management in addition may be appropriate, plus the re-establishment of peat-forming sedges like lesser pond-sedge *Carex acutiformis* or bottle sedge *Carex rostrata*, which could help restart peat formation (Hinzke *et al.,* 2021). Without soil amelioration, former agricultural sites over peat are unlikely to revert to bog.

Monitoring

Although many aspects of peatland restoration have been implemented for more than 40 years and there have been many trials, experiments and much monitoring, every site is different. It is important to ensure you have value for money and that restoration trajectories match objectives and targets. Monitoring therefore needs to be considered at the outset (see Overarching Principles - Monitoring).

Thom *et al.* (2019) provide a wide range of monitoring methods for hydrology, peat surfaces, peat chemistry, vegetation and animals. Monitoring can vary from detailed scientific approaches, to surveillance assessing the efficacy and progress of restoration measures, or a mixture of the two. In general, all restoration measures require regular examination to ensure they are functioning as designed. Repairs and replacements may be needed on a regular basis. Thom *et al.* (2019) provide some monitoring forms to assist this process.

The most often used monitoring methods are:

- Fixed point photography;
- Dipwells for hydrological monitoring (preferably together with a rain gauge), with or without data loggers (volunteers can measure these regularly too);
- Vegetation quadrats;
- Remote sensing and aerial photography; and
- Breeding bird surveys.

Figure 18

Dipwell transect across dammed grip plus automated water sampler for DOC measurements, Bowland.

Photo credit: Penny Anderson Associates.

More recent research has looked at using satellite remote sensing to measure features like bog breathing (peatland surface motion) to monitor peatland condition (NatureScot Research Report 1269: Using peatland surface motion (bog breathing) to monitor Peatland Action sites).

As some restoration could be linked to Biodiversity Net Gain (BNG), it is important for monitoring to focus on meaningful data collection and analysis geared to bog habitat rehabilitation and the Bog Quality Index (O'Rielly, 2015; Adamson, 2023), thus contributing to the restoration community's knowledge, rather than referring only to BNG condition criteria.

It is essential not only to obtain before and after data, but also to learn from and apply the findings.

Constraints, limitations and opportunities

For an overview of the general constraints, limitations and opportunities, see the list under Site Assessment (page 7).

Reaching inaccessible areas of bogs often depends on using Low Ground Pressure (LGP) vehicles or possibly helicopters; this needs careful costing and planning. LGP vehicles can speed up or slow down successful restoration. Experience suggests that 1.9 m wide tracked vehicles provide the best results, with 1.5 m as a minimum. 1.3 m tracks usually result in a vehicle getting bogged down, which can cause significant damage (and cost).

Every effort needs to be made to avoid damaging bog habitats in development projects by seeking areas with minimal peat cover for infrastructure. Peat can be protected *in situ* by using floating roads and pads for turbines; this would retain its carbon but lose the buried habitat and affect the hydrology of the adjacent peat mass. Local re-use of excavated peat may be feasible. For example, if there was deep gullying and patchy peat loss, then it might be possible to use the underlying peat to fill gullies or large drains and reinstate an even bog surface. Peat should not be handled loose but kept in intact turves as far as possible to preserve its structure and consistency. Its wetness needs to be maintained. For example, a wind farm development on Oswaldtwistle Moor (Mid Pennines) aimed for minimal peat handling. Intact turves with a separate 500 mm thick vegetation layer were removed and replaced, in the correct order, into adjacent large drains to block them (see Conservefor Ltd: Peat translocation Oswaldtwistle Moor Windfarm).

In the construction of many wind farms, peat removed from the infrastructure areas has been spread along road berms and verges and then reseeded (Figure 19). This is not recommended, as this shallow peat will decompose losing its mass and carbon very quickly and will not support any kind of bog community. It would be better to use subsoils along berms and verges, and to keep any peat for use in wet environments to maintain its properties as much as possible.

Figure 19

Loose peat being laid along track edges for a wind farm access – not recommended.

Photo credit: Penny Anderson.

Complete translocation of bog habitat to a new site is not possible. At an opencast coal site in Durham, there was an early attempt to translocate 1 m deep peatland turves by excavating parallel trenches 3.5 m wide and 7 m apart, into which pairs of turves were fitted adjacent to each other (Anderson, 2003). Although the cottongrass and heather community remained fairly intact after this process, the intervening vegetation that developed on the unexcavated material, with a thinner peat covering, bore little resemblance to a blanket bog community. Thus, the blanket bog habitat, functionality and hydrology were totally disrupted. Other factors could also be important in such situations such as the risk of slumping of thick peat turves, the structure of sub-turf peat that needs to be maintained, and the retention of necessary hydrological conditions.

Bog restoration is mostly not immediate. In some cases on severely damaged bog, peatland restoration will need to be phased over many years to elevate water tables to sustainable levels, requiring possibly multiple applications of restoration measures. The more severely damaged the site, the longer it will take to reach good condition and become an actively peat-forming and carbon sequestrating site. Restoration should be planned for a 10–50+ year period.

The Peatland Code, developed and managed by the IUCN Peatland Programme, is a voluntary certificate standard for UK peatland projects wishing to market the climate benefits of peatland restoration (IUCN Peatland Programme: Peatland Code). It provides assurances to carbon market buyers that the benefits being sold are real, quantifiable, additional and permanent. It may provide an opportunity for financial support for a project. The project has to be implemented to achieve the required restoration trajectory before the credits can be sold.

Figure 20

Ten year progress of a deeply eroded grip after blocking. Bowland, part of United Utility’s SCaMP project.

(a) 2007 pre blocking (b) 2009 after dams installed (c) 2012 (d) 2013 (e) 2017

Photo credit: Penny Anderson Associates.

Case studies

There are a wide range of bog restoration projects throughout the Republic of Ireland and the UK, most of which have informative websites. Many have included experimental approaches and have taken peatland restoration in different directions depending on the issues, geography, policy context and financial background. New practices are being continually developed, so consult all the relevant websites and guidance documents.

1. Blanket bog restoration in the North York Moors and Yorkshire Dales

   Yorkshire Peat Partnership progress reports

2. Blanket bog restoration in the Peak District, South and West Pennines

   Moors for the Future Partnership – Resources

3. Blanket bog restoration in Cornwall, Dartmoor and Exmoor
   - South West Peatland Partnership - what we do
   - The National Trust – Case study: Peatland restoration on Dartmoor
   - Exmoor Mires Partnership

4. Blanket bog and raised mire restoration in Scotland

   Nature Scot - Peatland ACTION - Delivering peatland restoration across Scotland

5. Peatland restoration projects in Wales
   - The National Trust - Welsh Peatland Sustainable Management Scheme Project
   - Lost Peatlands Project/Prosiect Adfer Mawndiroedd

6. Peatland restoration in Northern Ireland
   - NI Water – We're protecting and restoring peatlands
   - Ulster Wildlife – Tyrone bog to be transformed into thriving peatland restoration hub

7. Blanket bog and raised mire restoration in Republic of Ireland
   - Coillte – Peatland Habitat Restoration
   - Bord na Móna – Restoring raised bogs for a greener future
   - Resources at: National Parks and Wildlife Service publications
   - Irish Peatland Conservation Council – Ireland's Peatland Conservation Action Plans
   - Blanket bog restoration in Republic of Ireland from afforestation Energy Efficiency (renewable energy information and support): The Importance of Blanket Bog Restoration in Ireland

8. Raised mire restoration in Lancashire
   - The Wildlife Trust for Lancashire, Manchester and North Merseyside – Restoring our precious peatlands
   - Natural England – Restoration scheme for Bolton Fell Moss (MRP001)

9. Restoration of Shropshire mosses
   - Natural England – Rewilding the Marches Mosses – Britain's third largest raised bog
   - Shropshire Wildlife Trust – Restoring one of our rarest habitats – Marches Mosses BogLIFE project

10. A selection of case studies from England, Wales, Scotland, Northern Ireland, and the British Overseas Territories

    IUCN Peatland Programme: UK Peatland Restoration – demonstrating success

Biographies

Penny Anderson

Penny is an ecologist who specialised in peatland restoration for over 40 years as part of her consultancy work at Penny Anderson Associates. She focused particularly on blanket bog restoration, working throughout the UK and in Ireland for multiple landowners, interests and projects, but especially for water companies and on wind farms.

Liz Allchin

Liz has thirty years of experience in ecology, much of which has been in researching and designing habitat management and restoration. Her knowledge of bog restoration has mostly been gained from working on restoration of open cast mining sites and habitat management plans for wind farm projects.

Mark McCorry

Mark McCorry is an ecologist based in in Co. Laois in Ireland. He has been working with Bord na Móna for 15 years, planning and implementing raised bog restoration and rehabilitation, and has worked on numerous bog restoration projects.

Amanda Ophof

Amanda is an ecologist who has worked on habitat restoration throughout her career. She currently works on peatland restoration across Scotland, focusing on the technical and delivery aspects of rewetting blanket, raised and afforested bogs.

Mike Perkins

Mike Perkins works as a Principal Ecologist for OS Ecology in the northeast of England. Currently, much of Mike's work focuses on habitat restoration plans for peatland and wetland sites in Northumberland and the Pennines. He was formerly a Senior Adviser on protected sites and peat restoration within the Natural England - Nature for Climate Peatland Grant Scheme (NCPGS) and was one of the Natural England Product Owners for Biodiversity Net Gain (BNG).

Josh Styles

Josh is the director of Styles Ecology Ltd and a botanical specialist whose expertise extends especially to phytosociological recovery on mires. He has worked for many years over a large spectrum of ombrogenous bogs and continues to advise individuals, non-governmental organisations and Natural England around their restoration and recovery.

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Penny Anderson Associates Ltd.

Penny Anderson Associates Ltd (PAA) is one of the UK's most respected ecological consultancies, with a track record of professional excellence since its establishment in 1972. Based in Buxton in the Peak District, PAA brings together an interdisciplinary team of ecologists, hydrologists, soil scientists, geomorphologists and GIS specialists to deliver high-quality, science-led ecological advice and solutions across the UK and overseas. Over five decades, the company has built a reputation for integrating robust ecological science with practical land-management outcomes. Its work covers a wide range of biodiversity and environmental services, including habitat survey and assessment, ecological impact assessment, hydrology, sustainable land management and restoration planning. PAA is particularly recognised for its expertise in moorland and peatland ecology, including the assessment and restoration of degraded upland habitats to support biodiversity, carbon storage, water quality and climate resilience.

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