IUCN National Committee United Kingdom

Peatland Programme

Forest to Bog Restoration

demonstrating success

Demonstrating Success is a series of publications – produced by the IUCN UK Peatland Programme – to showcase practical examples of peatland restoration and sustainable management. The series presents an introduction to the topic followed by a set of illustrative case studies that have successfully demonstrated high-quality conservation actions, restoration activity, community engagement and innovative ways of engaging people in conservation action.

Forest to Bog Restoration

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The International Union for the Conservation of Nature (IUCN) is a global organisation, providing an influential and authoritative voice for nature conservation.
The IUCN UK Peatland Programme promotes 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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Forsinard flux tower at Dyke (© Mhairi Coyle)

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1. INTRODUCTION

UK peatlands are rare habitats of international significance. They are of high importance for both biodiversity and climate change challenges. They host rare, threatened, and specialised examples of flora and fauna, and have sequestered and stored carbon from the atmosphere for millennia. Peatlands play a significant role in flood management and are vital for water security. They ensure a reliable supply of high-quality fresh water, supporting downstream habitats and provisioning potable supplies. Using palaeoecological and archaeological techniques, peatlands can also be read like history books of the landscape containing climatic, vegetative and anthropological archives.

However, these benefits are all placed at risk by the degradation of our peatland landscapes. Currently it is estimated that some 80% of peatlands in the UK are degraded in some way due to damaging past and present practices such as drainage, rotational burning, peat extraction, conversion to agricultural use and plantation forestry[1,2]. It is the latter of these that will be the focus of this instalment of the IUCN UK Peatland Programme *Demonstrating Success* series.

Plantation forestry on peatland is largely historical and has had significant adverse impacts on the habitats and services they provide, both on and off site, and is now seen as an unsustainable practice under forest policy[3]. Like other areas of peatland restoration, the practice of ‘forest to bog’ restoration has advanced significantly over the past 30 years. However, compared to other restoration activities it can be a much more involved, complex, and costly undertaking due to the comprehensive degradation of the peatland habitat and added complexities of removing the forestry and changing the use of the land.

Even so the past decades have seen forest to bog restoration advance greatly in the UK, thanks to the collaborative nature of the restoration community. Each new project has advanced in an evolutionary manner, carrying forward lessons learnt from previous projects in a spirit of knowledge sharing between partnerships and sectors. The result of this work, supported by scientific research, clearly demonstrates that it is possible to rehabilitate these damaged areas of peatland and return beneficial climate and biodiversity functions, even within a relatively short 10–20 year period[4].

1.1 What is meant by Forest to Bog restoration?

The term ‘forest to bog restoration’, although increasingly common place, can cause some confusion if not defined. In most cases, including in the context of this publication, it is referring to the removal of plantation (predominantly conifer) forestry from areas that were once open peatland habitat,

1. Bain, C.G., Bonn, A., Stoneman, R., Chapman, S., Coupar, A., Evans, M., *et al. IUCN UK Commission of Inquiry on Peatlands*. IUCN UK Peatland Programme. 2011.
2 Evans, C., Artz, R., Moxley, J., Smyth, M.A., Taylor, E., Archer, E., *et al. Implementation of an emissions inventory for UK peatlands*. Centre for Ecology and Hydrology. 2017. pp. 1-88.
3 IUCN UK Peatland Programme. *POSITION STATEMENT: Peatlands and Trees*. https://www.iucn-uk-peatlandprogramme.org/sites/default/files/2020-04/IUCN%20UK%20PP%20Peatlands%20and%20trees%20position%20statement%202020_0.pdf [Accessed 09/01/2024]
4 Anderson, A.R., Ray, D. and Pyatt, D.G. Physical and hydrological impacts of blanket bog afforestation at Bad a′ Cheo, Caithness: the first 5 years. *Forestry*. 2000. 73: 467-478.

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and the subsequent restoration of peatland structure and function. What it does not refer to is the removal of native, naturally wooded peatland habitats such as wet woodland or fen carr woodland. The removal of plantation forests on peatlands is not ‘deforestation’ within the context of international regulations aimed at protecting natural forests from conversion to agriculture. UK forest policy recognises the importance of peatlands and there is a presumption against planting on peat soils. Devolved country-level forest policies recognise that existing forestry plantations on peatlands, which no longer meet sustainable forestry principles, can be removed to enable peatland restoration for biodiversity and climate benefits. Much of this former planting practice took place on raised or blanket bog habitats so bog habitat is the most common restoration end target. However, there are also examples where planting and restoration has taken place on fen peatlands.

1.2 Historical context and summary of problems

Much of the forestry on peatlands in the UK was planted during the last century. At the time, public policy was aimed at replenishing forest as a strategic timber resource encouraging peatland drainage and plantation establishment on land considered to be of lower value for other purposes[5,6]. Today, however, we know that the value of these peatland ecosystems lies within their biodiversity importance and the suite of other ecosystem services they provide.

The most recent estimate places approximately 18% (439,410 ha) of the UK’s peatlands under forestry[7]. It is difficult to confirm what peat depth this area applies to, but the consensus is that the majority of this area is made up of conifer plantation on drained deeper peats (generally >30-50 cm dependant on administrative region)[2]. There could be significant areas of as yet unquantified plantation on shallower peats, the removal of which may be important in the recovery of hydrological function and biodiversity of peatlands.

The impacts of afforestation on peatlands are multifaceted and universally degrading. Drainage, fertiliser application and tree growth have all been shown to have potential adverse and long-term impacts on biodiversity and functionality of peatlands both directly under planted trees, in the surrounding landscape and in connected freshwater habitats[8,9]. The specially adapted plant and animal communities and several important avian species that make their home in open bog landscapes are lost, displaced, or replaced with a less diverse range of more generalist species. In what is known as the ‘edge effect’, peatland bird species have been shown to avoid otherwise near natural areas of peatland up to several hundreds of metres away from the forestry edge[10].

5 Campbell, D., Robson, P., Andersen, R., Chapman, S., Cowie, N., Gregg, R., *et al*. Peatlands and forestry. *IUCN UK Peatland Programme’s Commission of Inquiry on Peatlands.* 2019. pp 10-21.
6 Sloan, T.J., Payne, R.J., Anderson, A.R., Bain, C., Chapman, S., Cowie, N., *et al*. Peatland afforestation in the UK and consequences for carbon storage. *Mires and Peat.* 2018. 23: 1-17.
7 Artz, R., Evans, C., Crosher, I., Hancock, M. Scott-Campbell, M., Pilkington, M., *et al*. *The State of UK Peatlands: an update.* 2019. https://www.iucn-uk-peatlandprogramme.org/sites/default/files/2019-11/COI%20State_of_UK_Peatlands.pdf
8 Stroud, D.A., Reed, T.M., Pienkowski, M.W. and Lindsay, R. *Birds, bogs and forestry: The peatlands of Caithness and Sutherland*. 1988. Nature Conservancy Council.
9 Payne, R.J., Anderson, A.R., Sloan, T., Gilbert, P., Newton, A., Ratcliffe, J., *et al*. The future of peatland forestry in Scotland: balancing economics, carbon and biodiversity. *Scottish Forestry*. 2018. pp.34-40.
10 Wilson, J.D., Anderson, R., Bailey, S., Chetcuti, J., Cowie, N.R., Hancock, M.H., *et al*. Modelling edge effects of mature forest plantations on peatland waders informs landscape-scale conservation. *Journal of Applied Ecology*. 2014. 51: 204-213.

Determining the carbon balance impact of plantation forestry on peatlands involves assessment of several pathways which are not all fully quantified, but there have been several major greenhouse gas balance studies that shed some light. The effects of forest plantations on peatlands are explored in the 2019 update to the Commission of Inquiry on peatlands and in the literature review, '*Peatland afforestation in the UK and consequences for carbon storage*'[9]. In summary, current evidence indicates that following afforestation there is a loss of carbon from the peatland carbon stock and a gain in tree carbon sequestered from the atmosphere. Whether tree uptake is sufficient to outweigh the losses from the peat carbon stock is still unclear and will likely be site specific depending upon local hydrology and the success of interventions to drain the peat. Currently plantation forestry ecosystem carbon values include the value of the peat soil carbon layer. Peat layers, however, pre-date plantation and it is likely that planting results in carbon loss[9]. Therefore, the carbon of the peat layer should be discounted from forestry assessments to enable a fair comparison between forestry and open peatland.

Any net climate benefit from trees on peat does need to be considered alongside the fact that the gain is significantly less than would be achieved if the trees were not planted on peat soils. There is consensus that even with our current knowledge limitations, the known carbon sequestration potential of an intact peatland and longevity of that carbon store indicate that the most significant climate benefit would be gained by having healthy functional peatlands with forestry located on mineral soils.

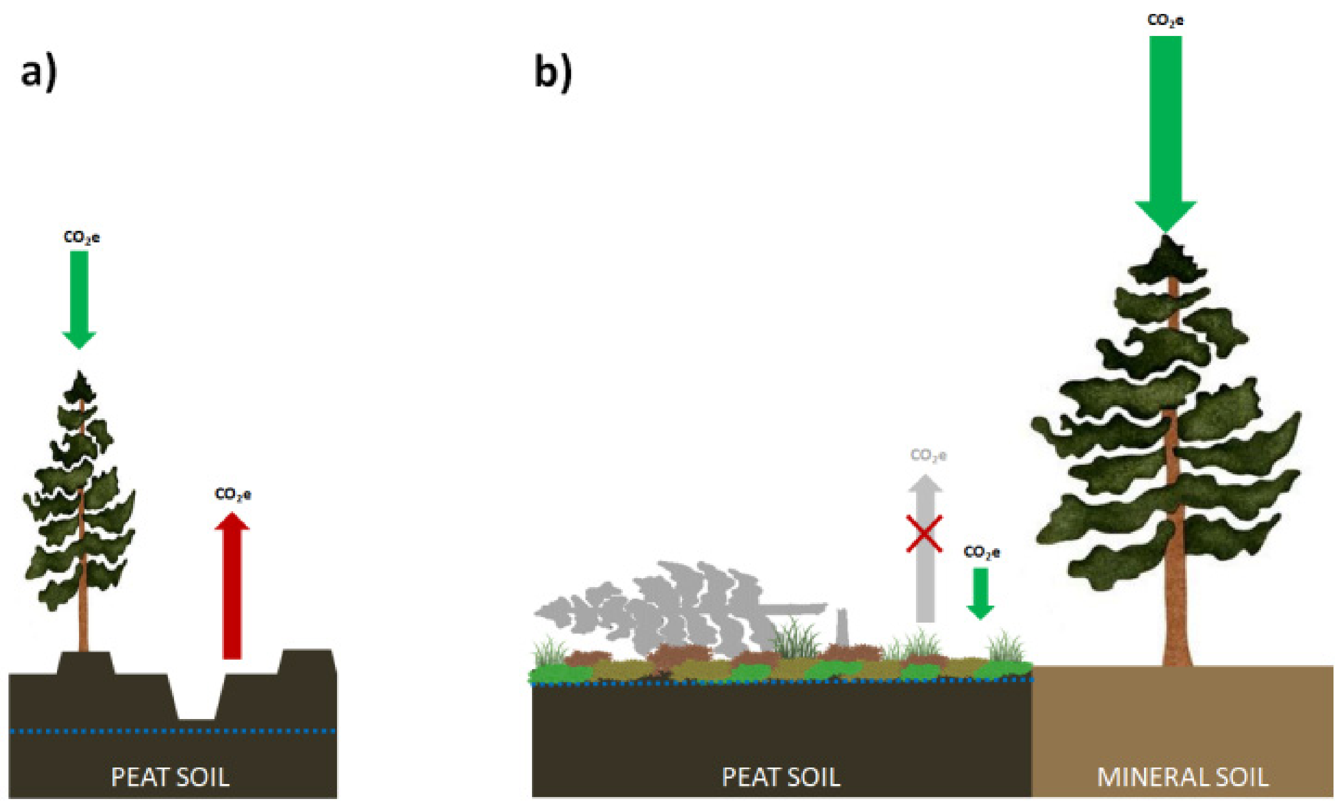

FIg 1. Land use scenarios for afforestation - taken from IUCN UK PP POSITION STATEMENT: Peatlands and Trees

Scenario a) Peat soils are drained and both the carbon sequestration capacity of the tree and the carbon sink capacity of the peatland are compromised.

Scenario b) The optimal land use scenario for carbon and peatland biodiversity would be to conserve open peatland habitat and restore afforested peatlands to health whilst maintaining and afforesting mineral soils where tree growth is not limited by hydrology or nutrient availability.

Note: Afforestation of mineral soils need not be in close proximity to peat soils and if this was the case, care would be needed to ensure the high water table in the peat had been stabilised before adjacent tree cover was put in place to avoid seeding into the drained peat.

2. IMPACTS

2.1 Hydrology and topography

Peatlands, particularly raised and blanket bogs, are not naturally conducive to tree growth. Therefore, a significant amount of preparatory work was often required to turn them into viable timber plantations. This was particularly true of drainage which was historically very intensive on afforested sites.

Whilst saplings are able to establish on an intact bog, it would have tended to be too wet for them to thrive, an important consideration for a commercial crop. To establish the saplings, many bogs were first ploughed, altering the surface topography. Ploughing created higher and drier ridges, where the trees could be planted, and furrows would act as drainage channels[5,9]. These furrows were then linked to main collecting drains dug at either end of the forestry block. The drains lowered the water table so that the tree roots grew deeper beyond the ridges. However, this was not the only way in which the normally positive water balance of a bog was disrupted on afforested sites. The trees themselves, once established, increased drying pressure through two further mechanisms. Firstly, by transpiration, drawing water up from their roots, and secondly, by interception, as the canopy closes, thus reducing the amount of rainfall which reached the peat surface[6,11,12].

On the wettest sites the species of tree planted may have been altered to aid the drying of the site for a second rotation. For example, if ploughing and drainage was insufficient in lowering the water table enough, then lodgepole pine (*Pinus contorta*) may have been planted, as they are adapted to growing in wetter conditions through the capability to transfer oxygen to their root systems[5,13].

The combined impact of these drying pressures mean that the drainage impacts experienced by afforested peat is particularly intense compared to other situations where the peat has experienced drainage. Oxidation and subsidence are keenly experienced under plantations, as is peat shrinkage, with cracking and deep fissures opening up in the peat surface and the peat mass itself becoming significantly denser[4,6]. Afforestation also results in significant differences to porewater chemistry in comparison to natural sites, and the ability to restore the water table may vary between bog types[14].

2.2 Biodiversity impacts

Conversion of open peatland habitat to dense blocks of plantation forestry has a significant negative impact on peatland biodiversity. The most obvious impact is the direct loss of habitat beginning with the digging of ditches and ploughing of the peat surface. This causes a vegetative loss which worsens as the plantation establishes. Drying and nutrient enrichment, the latter due to fertilisation and oxidation, disrupt the conditions needed for peatland species, like *Sphagnum* mosses, to thrive.

11 Sarkkola, S., Hökkä, H., Koivusalo, H., Nieminen, M., Ahti, E., Päivänen, J. and Laine, J. Role of tree stand evapotranspiration in maintaining satisfactory drainage conditions in drained peatlands. *Canadian Journal of Forest Research*. 2010. 40: 1485-1496.
12 Lewis, C., Albertson, J., Zi, T., Xu, X. and Kiely, G. How does afforestation affect the hydrology of a blanket peatland? A modelling study. *Hydrological Processes*. 2013. 27: 3577-3588.
13 Coutts, M.P. and Philipson, J.J. Tolerance of tree roots to waterlogging: ii. Adaptation of Sitka spruce and lodgepole pine to waterlogged soil. *New Phytologist*. 1978. 80: 71-77.
14 Howson, T., Chapman, P.J., Shah, N., Anderson, R. and Holden, J. A comparison of porewater chemistry between intact, afforested and restored raised and blanket bogs. *Science of the Total Environment.* 2021. 766: 144496.

Pressures on peatland vegetation further increase as the plantation establishes. A closing canopy restricts light and finally, in conifer plantations, the surface is carpeted with fallen needles. Any remaining bog vegetation is found to have fully retreated to the wetter furrows[9].

The change in hydrological conditions, nutrient cycling and vegetation composition also impacts upon below ground microbial diversity, with specialist microbe and fungi populations being replaced with more generalist species[(9,15)]. This is also true of macrofaunal diversity of invertebrate and avian species[(5,16)]. The siting of forestry on peatland has also been linked to an increase in pathogen-carrying invertebrates, namely deer ticks (*Ixodes ricinus*), as large herbivores such as deer gravitate to these areas for shelter[17].

There are also indirect and wider impacts of afforestation on biodiversity within the landscape. These are often referred to as 'edge effects' as they extend beyond the edges of the forestry plantations. Edge effect impacts have been studied on ground nesting wading birds such as the golden plover, which favour open bog landscapes. It has been found that these species will avoid nesting in areas up to 700 metres away from forestry blocks. This is an instinctive reaction to avoid predation of themselves or their young. The cumulative impact of multiple blocks of forestry within a landscape is that large populations can be displaced from otherwise favourable condition peatland. Similarly, a more recent study looking at the movements of predator species such as foxes (*Vulpes vulpes*) has shown that related forestry infrastructure - roads and tracks - can greatly extend their range and hunting territory[18].

Finally, another often overlooked impact of plantation forestry is the 'creep' of trees that have established themselves through seeding onto areas adjacent to the originally drained block. Although slower to establish without the intensive drainage management, if a sufficient density of self-sown trees is reached, they can start to negatively impact upon the hydrology and biodiversity of the peatland, expanding outwards from the plantation boundary.

2.3 Carbon and climate impacts

Determining the impact of afforestation of peatland carbon stocks and climate regulation is complex. Whilst there is agreement on the mechanisms involved regarding the capture, storage and loss of carbon, consensus on how these mechanisms interact and operate in the whole carbon balance is yet to be reached. This is especially true when the prospects of multiple forest rotations (restocking), the fate of harvested timber and the role of methane are also considered.

Undisturbed peat bogs will slowly accumulate carbon by the uptake of carbon dioxide through

15 Creevy, A.L., Andersen, R., Rowson, J.G. and Payne, R.J. Testate amoebae as functionally significant bioindicators in forest-to-bog restoration. *Ecological Indicators.* 2018. 84: 274-282.
16 Fernandez, A.P., Andersen, R., Artz, R., Boyd, K., Cowie, N. and Littlewood, N. Moth responses to forest-to-bog restoration. *Mires and Peat.* 2020. 26: 27.
17 Gilbert, L. Can restoration of afforested peatland regulate pests and disease? *Journal of Applied Ecology*. 2013. 50: 1226-1233.
18 Hancock, M.H., Klein, D. and Cowie, N.R. Guild-level responses by mammalian predators to afforestation and subsequent restoration in a formerly treeless peatland landscape. *Restoration Ecology*. 2020. 28: 1113-1123.

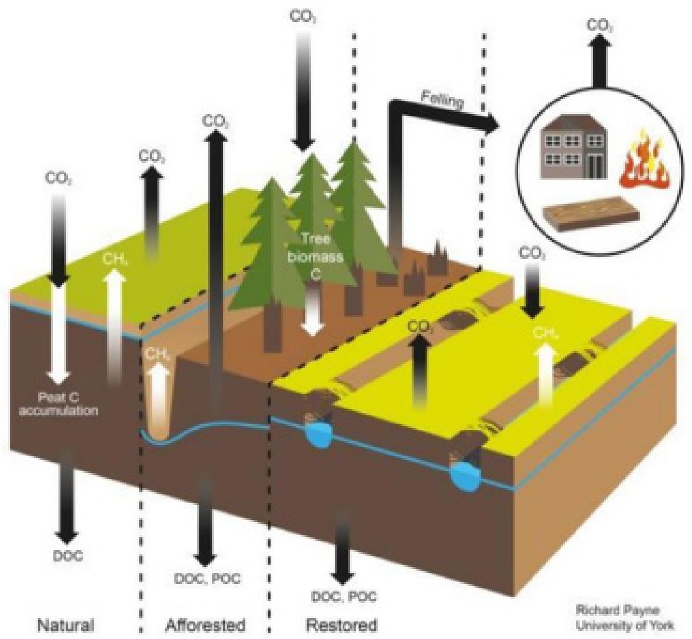

Fig. 2 Conceptual diagram of key carbon cycle pathways and changes with peatland afforestation and restoration © Richard Payne, University of York

Note that the arrow widths are indicative only as there is much uncertainty in their relative values.

CO2 = carbon dioxide; CH4 = methane; DOC = dissolved organic carbon; POC = particulate organic carbon

photosynthesis and laying down peat. They also emit some methane from the waterlogged anaerobic peat, often via vegetative conduits. Methane is a more potent greenhouse gas than carbon dioxide (with ~25 times the warming potential) but doesn't remain in the atmosphere for as long. When this is considered over centuries, the uptake of carbon by a bog has a net cooling effect on the climate.

Reviews of evidence have concluded that there is no carbon benefit to the establishment of woodland on shallow peat or organo-mineral soils[19]. Some studies have concluded or predicted that in certain situations on organo-mineral or shallow peat soils, afforestation can lead to a net benefit[20]. However, this either requires multiple rotations or it is unclear if the impacts of soil preparation, harvesting, restocking, felling, the associated infrastructure of this (tracks, transportation), and end uses have been considered[5]. The situation for deep peat soils is more ambiguous due to a lack of empirical evidence and opinion is divided as to whether forest growth is likely to compensate for losses of carbon from peat, and if so at what point tree carbon is likely to exceed peat carbon losses[29].

Equally, the long-term effects of deep drainage of peatland for forestry and the drying effect of timber crops on the peat deposit and carbon store are unclear. Evidence suggests that estimates on which current policy are based may have reached overly optimistic conclusions regarding the net impact of forestry activities on the peatland carbon balance[21]. These calculations are further complicated by the differing potential end uses for timber products with carbon turn over periods ranging from short (combustion for fuel) to medium (timber used in construction) time frames. In comparison, carbon stored in peat is captured over long (millennial) time scales.

19 Bavin, S., 2021. *How do soil properties influence carbon storage and sequestration in newly established woodland across the UK?* The Woodland Trust. 2021. www.britishecologicalsociety.org/applied-ecology-resources/document/20210403458/ [Accessed 09/01/2024]
20 Vanguelova, E.I., Crow, P., Benham, S., Pitman, R., Forster, J., Eaton, E. L., and Morison, J. I. L. Impact of Sitka spruce (Picea sitchensis (Bong.) Carr.) afforestation on the carbon stocks of peaty gley soils – a chronosequence study in the north of England. *Forestry: An International Journal of Forest Research*. 2019. 92: 242–252.
21 Young, D. M., Baird, A.J., Charman, D.J., Evans, C.D., Gallego-Sala, A.V., Gill, P.J., *et al*. Misinterpreting carbon accumulation rates in records from near surface peat. *Scientific Reports*. 2019. 9: 1–8.

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2.4 Water quality impacts

Most research looking at the impacts of afforested peatlands on water quality has focused mainly on the effects of restoration practices rather than the afforestation itself. Where research has been carried out, the main observation has been an increase in exports of dissolved organic carbon (DOC). This is partly the result of drainage and oxidation of peat. A 2021 study that sought to quantify riverine DOC export across the whole of the UK was able to distinguish a clear impact of non-native conifer plantations on peat soils, estimating an annual carbon export of 45,000 t. This equated to 4% of the total but is of note when considering it only accounts for 1.5% of UK land use[22].

Ground-smoothing at Moss of Cree (© Stuart Evans)

22 Williamson, J.L., Tye, A., Lapworth, D.J., Monteith, D., Sanders, R., Mayor, D.J., *et al*. Landscape controls on riverine export of dissolved organic carbon from Great Britain. *Biogeochemistry*. 2023. 164:163-184.

3. FOREST TO BOG RESTORATION

Whilst it is important not to be too prescriptive, as each site and situation is different, the general process of forest to bog restoration takes place after the trees have been removed and can be simplified into three main steps: brash removal, surface reprofiling and rewetting. These steps have been arrived at as the result of studying early trials and as the restoration process has evolved and some of the most important methods have been compared in replicated trials. The full learning from these trials will take some time as the complete restoration trajectory is a slow process, although significant benefits can be achieved within a few decades. In some locations, the process can be simplified into two stages of tree removal and rewetting. There are some examples of the entire process being undertaken as a single pass of a machine with large self-seeded trees being pushed into the peat and cross-tracked to reprofile the ground surface in a single process. The approach taken will be based on the limitations of the machinery available and the conditions of the site.

3.1 Felling

Felling methods will largely be determined by the existing forestry guidance, site access, ground conditions and the size and yield class of the trees. In some of the earliest examples of forest to bog restoration the trees were ‘felled to waste’ regardless of size. This involved either leaving the felled trees and crushing them into the peat surface or mulching them and spreading the remains over the peat surface, with drain blocking and rewetting taking place afterwards. At the time, reasons for this included a poor price and low demand for biomass in combination with a younger and poorly developed crop, sometimes in combination with limited access, making the harvest and removal uneconomic.

3.2 Brash removal

‘Felled to waste’ has now mostly been replaced with what is sometimes known as ‘enhanced felling’ where the whole tree is removed, resulting in a more effective restoration technique. Brash removal is important to limit nutrient input and to allow grazing access to prevent colonisation by undesirable vegetation or recolonisation by self-seeded trees. The nutrient status of the peatland is already altered during the establishment of plantations with the application of fertilisers but if the remains of trees and brash are left to decompose on site, this can further enrich the nutrient status[18,23]. This can then have consequences on the restoration trajectory, potentially slowing down the return to being a carbon sink.

3.3 Surface reprofiling and rewetting

More recent work has focused on how to treat the altered surface topography. In some of the oldest examples of forest to bog restoration, the ridges and furrows created by ploughing might have been left, infilled with the remains of trees and incrementally dammed using peat during the rewetting process. However, it has been found that the uneven topography created ecohydrological gradients too harsh for the establishment of target bog vegetation, with the higher and drier ridges favouring non-bog species which ultimately had a negative impact on the establishment of typical bog vegetation in the furrows[18]. There is also evidence that the very wet furrows created as a result of the

23 Gaffney, P.P., Hancock, M.H., Taggart, M.A. and Andersen, R. Restoration of afforested peatland: Effects on pore-and surface-water quality in relation to differing harvesting methods. *Ecological Engineering*. 2022. 177: 106567.

damming and rewetting were becoming methane emission 'hotspots' across ~50% of the restoration areas, slowing the recovery of the site's climate regulation functions[24].

To address this the site must be reprofiled. The most common way to do this is to 'cross track'. Low pressure tracked vehicles are driven over the ridges to flatten them into the furrows. Often the remnant tree stumps also need to be dealt with as part of this process. There is a lot of discussion about how best to do this whilst causing minimal disturbance to the peat, but methods used also strongly depend on the depth of peat and the species of tree. Stump flipping is one method that is commonly employed on former Sitka spruce plantations on deeper peat deposits, where an excavator is used to flip the stump and root plate out of the ridge and into the furrow. This method does cause a lot of ground disturbance and is not recommended on shallower peat deposits, as it is more likely to expose the underlying non-peat substrate. Alternatively, another method that has been trialled is stump auguring which drills the stump into smaller pieces. This method is less disruptive to the peat and is more suited to former lodgepole pine plantations where the root ball would otherwise need to be excavated rather than flipped, or on shallower peat deposits, as there is less risk of exposing the substrate.

3.4 Post-restoration management

The final aspect of forest to bog restoration that needs to be considered is the problem of conifer regeneration from dormant seeds which can grow rapidly and densely. Whilst recovering water tables will eventually deter the growth of such seedlings, the early stages of rewetting are vulnerable to inundation from seedlings which can themselves lead to water depletion and inhibit the recovery of natural peatland water tables. Various techniques from herbicides or physically pulling seedlings out of the peat have been used.

3.5 Cost of forest to bog restoration

Forest to bog restoration can be considerably more costly than other forms of peatland restoration due, in part, to the impacts to the peatland system being more severe and requiring multiple stages of treatment. It is also difficult to generalise costs of restoration as the process can vary depending on the nature of the site and the forestry impact. In some cases, costs can be offset by selling felled timber, but the returns can also vary and predicting these is difficult. As a result, costs can range from a modest profit to a net cost in excess of £4,000 per ha (where trees are mulched rather than sold)[5,25].

Assuming costs at the higher end of the range and recognising that the majority of forested peatlands are commercial plantations on deep peat, restoring 80% of the forested peatlands to naturally functioning peatland habitat could cost in the region of £1.4 billion. This is over £1 billion more than the current combined 2020-2030 funding pledges for peatland restoration from NatureScot, Natural England and Natural Resources Wales[26,27,28].

There can be significant one-off and ongoing costs involved with forest to bog restoration after the trees are removed. Firstly, significant alterations to the peatland surface structure and hydrology, as a result of forest management, have to be removed and reversed through methods such as reprofiling, stump flipping, drain damming and bunding. This can cost between £800-£1,000 per ha depending on the level of intervention. There is then the ongoing task of removing self-seeded 'regeneration' saplings by hand which can cost an additional £150 per ha.

It should be said that these figures are an approximation with costs from a limited number of studies, and the uncertainty around exactly how much of the afforested peatland is both commercial plantation and on deep peat. However, what is clear from these figures is that the cost of restoring afforested peatlands will be high, prohibitively so for many landowners, especially if the removal of trees is unprofitable.

3.5.1 The role of private finance

Unlocking private finance could help spread the burden of costs between the public and private sectors, and allow more speedy delivery of biodiversity and climate goals. Private finance has two major potential roles. Firstly, it can reduce the burden on public funds of financing the capital restoration works. Secondly, private investment over the lifetime of a project could encourage landowners to invest in, and undertake, restoration themselves, as additional financing could make the forest to bog management economically viable.

The Peatland Code supports private funding initiatives for restoration of degraded peatlands by providing a quality reputable standard with a process of accreditation, registration and verification. At the time of publication, the Peatland Code does not include forest to bog restoration as eligible. There are several issues which need to be addressed before the Peatland Code could adopt forest to bog restoration:

- Currently there is a limited dataset from which to derive specific emission factors for peatland restoration on former plantation forestry sites. However, it is widely acknowledged that forest to bog restoration can return a severely degraded clear-felled, drained and greenhouse gas (GHG) emitting peatland (post-harvesting) into a secure long-term carbon store again (and likely sink over a longer time frame). Whilst there is currently insufficient data to provide specific forest to bog emissions factors, GHG flux data is currently being gathered that will inform these.
- Currently there is not an agreed accounting method under the UK GHG Inventory for forest to bog restoration.

24 Mazzola, V., Perks, M.P., Smith, J., Yeluripati, J. and Xenakis, G. Seasonal patterns of greenhouse gas emissions from a forest-to-bog restored site in northern Scotland: Influence of microtopography and vegetation on carbon dioxide and methane dynamics. *European Journal of Soil Science*. 2021. 72: 1332-1353.
25 Glenk, K. Sposato, M., Novo, P., Martin-Ortega, J., Roberts, M., Gurd, J., Shirkhorshidi, M. The costs of peatland restoration revisited - March 2022 update on database based on the Peatland Action Programme in Scotland. *SEFARI Report*. 2022.

26 NatureScot. *Peatland ACTION Project Delivering peatland restoration across Scotland*. https://www.nature.scot/climate-change/nature-based-solutions/peatland-action-project [Accessed: 09/01/2024]
27 DEFRA. *Nature for people, climate and wildlife*. 2021. https://www.gov.uk/government/publications/nature-for-people-climate-and-wildlife/nature-for-people-climate-and-wildlife [Accessed 09/01/2024]
28 Cyfoeth Naturiol Cymru / Natural Resources Wales. *National Peatland Action Programme, 2020-2025.* 2020. https://cdn.cyfoethnaturiol.cymru/media/692545/national-peatlands-action-programme.pdf [Accessed 09/01/2024]

4 Mapping and prioritisation

Given the scale of forest to bog restoration challenges, and the urgency of the biodiversity and climate crises, some thought also needs to be given to how areas that are to be restored will be prioritised. The first step of this will likely be a mapping and inventory project. Whilst there is an estimate for the amount of forested peatland in the UK, and an assumption that the majority of this is conifer plantation on deeper peats, the breakdown of this across the UK is not readily available, with the exception of England, where it is estimated that 60% of wooded deep peat (>40 cm) is conifer plantation. This not only makes it difficult to fully appreciate the scale of restoration needed, but also to estimate the investment (whether public or private) needed to address it. Mapping would then help to prioritise sites making sure that the public funds are diverted appropriately to sites that will gain optimal climatic, biodiversity and landscape benefits without prohibitive costs.

5 Monitoring and survey

Whilst forest to bog restoration has been undertaken for several decades there is still much to learn about the most appropriate and cost-effective treatments. There are a number of outstanding research questions which we consider to be pertinent:

- Further work is needed to better understand and define the different stages in the trajectory from plantation forest removal to near natural peatland conditions.
- Quantifying the impact of forest to bog restoration on biodiversity recovery and on ecosystem services is essential to understanding the benefits of the work but is also important in providing metrics that can be used to support private investment in restoration work.
- Research considering the long-term impacts of deep drainage and the drying effect of commercial plantations on peatlands would be useful.
- Further research is needed on the impacts, both positive and negative, on water quality in the post-deforestation and restoration period. This will help to better manage treatment of potable water supplies.
- We need to understand what erosion processes are acting on sites during the post-restoration recovery including the nature of these from overland flow, needle ice, wind and rainfall mediated erosion to peat pipe formation, and how these can be mitigated.
- Models need to be developed to prioritise areas for restoration also need data on the different modelling parameters.

These questions would ideally examine the differences between raised and blanket peatlands to ensure that variation between the habitat types are fully understood.

6 Summary

In summary, whilst considerable progress has been made in understanding the impacts of afforestation and mitigating these, it is important to also acknowledge that there remain gaps in the knowledge and areas where policy could be improved. Research should be targeted to the areas outlined in the previous section to ensure that the key outstanding questions can be answered. For future forestry planning it is important that the planting guidance is adhered to, particularly the avoidance of peat with depths >10 cm. Finally, it will be key to work alongside the Woodland Carbon Code to ensure that private finance can be delivered harmoniously alongside the Peatland Code to better achieve joint conservation outcomes.

Rhigos Mountains (© ScottishPower Renewables)

FOREST TO BOG — DEMONSTRATING SUCCESS 2024

CASE STUDY A: MARCHES MOSSES: A 20 YEAR STUDY

Forest to bog restoration in the drier lowlands shows promising results but is reliant on both effective rewetting and long-term post-restoration management

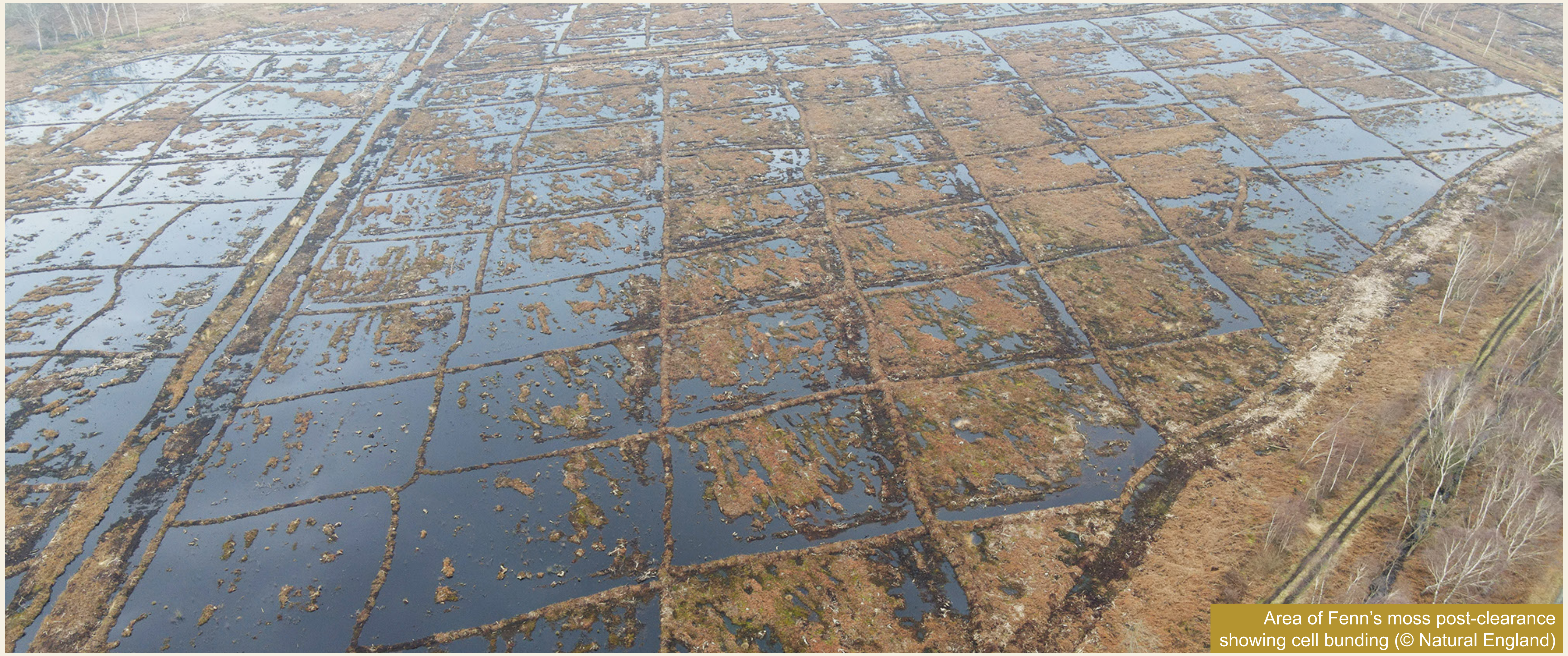
Background
The 1000 ha 'Marches Mosses' cover Fenn's, Whixall, Bettisfield, Wem & Cadney Mosses Special Area of Conservation (SAC) straddling the English/Welsh border. Before the centre of this lowland raised bog complex became a national nature reserve in 1991, it was commercially cut for peat and some marginal peats were converted to forestry. Cessation of burning on Bettisfield Moss in the 1950s led to the small areas of pines which had been planted in the 1920s self-seeding, progressively covering the moss, whilst in the 1960s Fenn's Moss was ploughed and planted with conifers. Largescale clearance of the 15-metre-high pine and birch canopy commenced in 2001 using a high-lead skyline, with the brash being sunk into brash mats in the very deep peat (7 m+) to support the 42 tonnes of forestry harvesting machinery. The project is funded through EU LIFE.

Challenges and opportunities
Despite the area not having been forestry ploughed and the few trackside ditches having been dammed, lateral drainage flow continued through the damaged 0.5 m surface peats, evidenced by typical summer water table drops of 0.5 m. As a result, wet heathland/bog vegetation was slow to come back. Moreover, frequent follow up management to control young birch and pine regeneration was required to keep the area open.

The cost of bunding ex-forestry areas worked out approximately double that for open peatland at approximately £4k per ha. The bunds in ex-forestry areas lack a turf cover and so are prone to birch tree regeneration which require repeated follow up treatment. Ground smoothing techniques are an area that has been found to work on deeper peats, but there remains the opportunity to explore different techniques for shallower peats where these techniques do not work.

Key successes and future ambitions
Research findings by Creevy *et al*. (2020) from the site show that the restoration to bog habitat is effective in returning the carbon sink function of areas damaged by commercial forestry although this took over 10 years to achieve with *Sphagnum* cover being the key factor. Although bog vegetation was slow to return in the post-restoration period, a 2019 survey recorded water levels that were significantly higher than the previous year (9.7–18.1 cm mean increase per management group relative to 2018) (Leader, 2020). In addition, the water table was less variable. As a result, large areas have been recolonised by hare's-tail cotton grass *Eriophorum vaginatum* and *Sphagnum* mosses and the uncut part once again supports a M18a NVC community characteristic of active bog habitat.

> *"Unless you have enormous amounts of rain, turning forest back to bog is a very long-term business, needing long-term staffing and funding. It took 20 years of scrub control and the development of the new bunding technique for dealing with damaged surface peats to achieve a successful result at Bettisfield Moss. New ground smoothing techniques are worth pursuing on deep peat but will not work on shallow peat. Also, it is much easier to get eradicate pine regrowth after tree clearance compared to birch, because of soil enrichment."*
>
> Dr. Joan Daniels



Area of Fenn's moss post-clearance showing cell bunding (© Natural England)

CASE STUDY B: BORDER MIRES: SMOOTHING THE WAY

How England's largest plantation forest co-exists alongside some of its finest peatlands

Background
The Border Mires are a collection of constrained mires in west Northumberland and east Cumbria, with over 50 sites comprising >2000 ha of mire habitat. The topography and climate in this area are ideal for peat formation, with some peat exceeding 10 m in depth. Having been exposed to less pressure from human activity than many areas, these mire habitats are among the best examples of peatland in England.

The history of the Border Mires is inextricably linked with that of Kielder Forest, the largest human planted forest in England, where planting started in 1926. While forestry activity reduced some pressure on the mires (e.g. farming, burning) many areas of deep peat were planted with trees or affected by drainage for adjacent planting. Even on areas left open, seed set by maturing crops resulted in encroachment by self-set conifers.

In seeking to address these scenarios Forestry England have trialled a technique previously used in Scotland, referred to as "stump flipping" or "ground smoothing", on a small mire restoration site in Kielder Forest. This technique involves the mechanical manipulation of the elevated material in the high ridges (stumps and degraded peat) to back-fill the adjacent furrows, thus creating a more uniform ground level (see image). Sometimes this is literally flipping over existing stumps, but it is far more nuanced than that in practice. With the ground surface levelled, deep trench bunds can then be installed at regular intervals along site contours to hold water within the site and raise the water table to the newly equalised ground level resulting in a much better mix of rewetted peat and shallow standing water than could be achieved without.

Challenges and opportunities
If only the larger drains are blocked, the water still flows along furrows. If the furrows are blocked as individual features, the water rises but can pass through the degraded peat of the ridges. Installing deep trench bunds bisects the furrows and ridges to hold more water within the site. However, this results in a site containing a series of linear pools with deep water not ideal for mire flora establishment.

The combination of ground smoothing and bunding make for an expensive per-hectare operation, especially if tree removal is first required.

Key successes and future ambitions
In practice, we discovered that the ground smoothing alone made an immediate and significant difference to site hydrology with water levels rising noticeably even before the bunds were installed. The work was only undertaken in early 2023 but early indications are extremely positive with water retention particularly good even through the very dry spring.

Forestry England are working with Forest Research to answer questions around the initial release of atmospheric carbon and methane from an operation that disrupts peat soils on a large scale and how these are balanced by the long-term benefits of the technique.

Creating a more uniform ground level – ground smoothing (© Forestry England)

Furrowed areas infilling with *Sphagnum* (© Forestry England)

"This trial has given us an opportunity to consider in detail how we can most effectively address our most heavily degraded deep peat sites, and then put it to the test. As with any trial, we have learned lessons at all stages of the process, and have more to learn still, but we have been incredibly pleased with the results we have seen. This trial has been just one part of developing our toolbox of options, especially when considering sites with higher levels of degradation, as we continue our commitment to peat restoration on the forestry estate."

Richard Guy, Forestry England

CASE STUDY C: BENMORE FOREST: A NEW ANGLE

A technique to rewet and un-modify ploughed ridges and furrows on a moderate slope

Background
The site at Meall an Lochain, Craggie, Benmore Forest, lies 240 m above sea level, and is 18 miles West of Lairg. The 32ha site was the third of five phases that now make up a landscape scale restoration project extending to over 430 ha in a continuous peatland unit. The site was planted in 1974, with trees aged 46 years old when felled. Peat on the site reached a maximum depth of ~1 m and had been ploughed and furrowed. An excavator specially adapted to work on wet ground and soft peat was employed. The 'stump flipping and ground smoothing' treatment was used to address the peat modifications and create the conditions for quick and effective recovery of peatland vegetation.

The restored peatlands are made up of several distinct types: relatively flat peatland with neighbouring ladder pools on a saddle, re-profiled hags on unflushed blanket bogs, and previously afforested unflushed blanket bogs on slopes of over 10 degrees.

Forestry and Land Scotland (FLS) began a program of peatland restoration in 2014, funded by NatureScot's Peatland ACTION fund. Since then, 'forest to bog' restoration has begun on over 80 FLS sites totalling over 4,000 ha.

Challenges and opportunities
The deeper root ball structure of lodgepole pine trees means that when the stumps are upturned, they can bring the deep 'catotelm' peat to the surface. This should be minimised or avoided as desirable peatland species tend to re-establish more slowly on this deep peat.

FLS will strive to improve and develop the approach and specifications following these principles:

- Enough and no more – do not over-engineer treatments;
- Minimise disturbance and compaction of peat;
- Remove modifications, not introduce more.

There is an opportunity to develop the stump-flipping methodology, as larger stumps create significant disturbance to the peat.

Key successes and future ambitions
Slope is often thought to be a limiting factor to peatland restoration, with slopes above 5 degrees considered unsuitable for restoration. This case study represents the first investigation of a steeper slope restoration effort and has given FLS high confidence that 'forest to bog' peatland restoration is possible on most afforested sites, including on peat depths down to 50 cm, and on slopes of up to at least 12 degrees.

The results showed that by June 2023, of the 9 positive indicator species present on the near natural bog, 6 were present in the restoring quadrats. The presence of *Eriophorum angustifolium* and *Sphagnum papillosum* suggests that the blanket bog will be restored here.

Modified excavator with widened tracks (© FLS)

"Using specialised machinery driven by experienced operators allowed the restoration specifications to be carried out in a more sensitive way than was previously possible. This meant that peat compaction and disturbance of existing vegetation was much lower than that achieved using conventional methods. This case study presents evidence that successful forest to bog restoration can be carried out on slopes greater than 10 degrees."

Ian McKee, Forestry and Land Scotland


Quadrat area showing expanding cover of *Eriophorum vaginatum* (© FLS)

FOREST TO BOG — DEMONSTRATING SUCCESS 2024

CASE STUDY D: DALCHORK FOREST: SHEARS HARVESTING

Employing a tree harvesting system to minimise peat disturbance and compaction on challenging restoration sites

Background
This case study describes the outcomes of harvesting trees from a 'forest-to-bog' peatland restoration site in winter 2017/18 using the shears method. Stump flipping and ground smoothing methods the same as those employed at Benmore were used post-harvesting.

The site at South Corries II, Dalchork Forest, lies 230 m above sea level, and is 8 miles north of Lairg. This 19ha site is part of a landscape-scale restoration project in Dalchork Forest, of which over 1,200 ha of forest-to-bog restoration has already been completed. Conventional harvesting systems use standard machinery designed to work on most, but not all, soil types. Harvesting trees on deep peat poses additional challenges, both in the machines' efficiency in terms of recovering as much timber as possible, and in limiting peat disturbance and compaction. Conventionally there are two types of machines involved. A harvester cuts and processes the trees, constructing brash mats to protect the soil, and a forwarder collects the timber and transports it to a loading facility at the forest road.

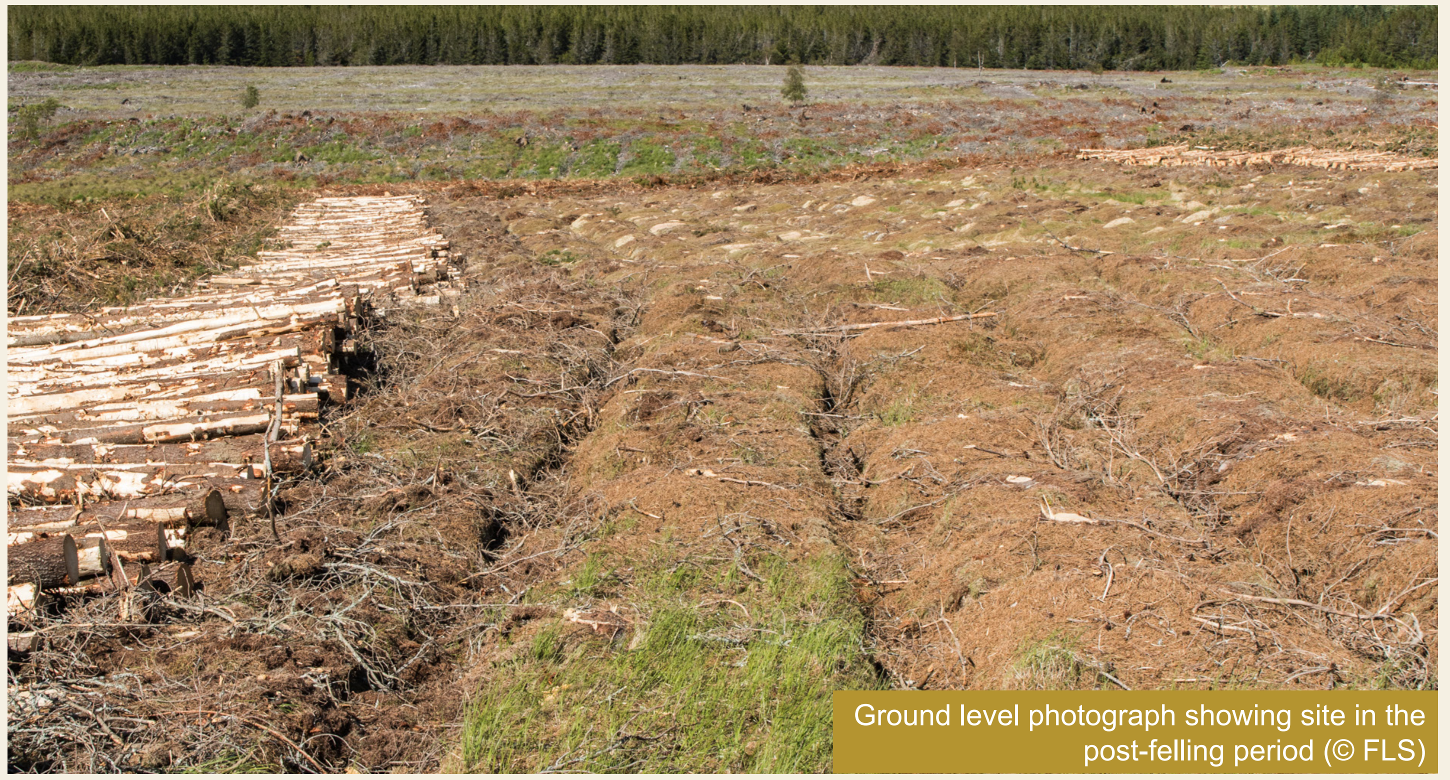
A limitation of this method is that on soft, wet peat, more timber is required to build a sufficient brash mat to support the machines, reducing the amount of timber recovered to roadside. Even when brash is brought from other parts of the site to supplement the mat, rutting can occur, damaging the peat underneath. This is common when the standing crop has a light or thin canopy, yielding less brash. Slow-growing and unhealthy crops that yield little brash are quite common on afforested peatlands.

The machines used included a standard forwarder (Komatsu 855 14 t forwarder with 800 mm tyres), a standard harvester (Doosan DX160 16 t excavator fitted with SP561 head and 1000 mm wide tracks) and a 13 t Komatsu excavator with purpose-built undercarriage, lengthened with 1900 mm wide tracks fitted. This machine had a shears harvesting head fitted (Westtech Woodcracker), capable of cutting the trees close to the ground to leave extremely low stumps. This is a harvesting 'system' because the method relies on the effective and efficient management and co-ordination of the three types of machines working in collaboration. A successful outcome depends on the capabilities of the machines, the skills and experience of the operators, and an ability to adapt the planning and workflow by responding to varying ground conditions and crop characteristics.

Challenges and opportunities
The main benefits of this system are reduced peat compaction and disturbance and less residual brash mat cover, making it easier to carry out rewetting works afterwards. The high standard of the brash mat created means that long extraction routes servicing extensive areas are possible so that fewer roads need to be built to reach remote sites. A neighbouring stand was subsequently harvested using this system, with an extraction distance of 2.5 km to the furthest point.

Key successes and future ambitions
By September 2022, four and a half seasons after rewetting, *Sphagnum* mosses were starting to exhibit their characteristic structural forms and *Betula nana*, a nationally rare birch species, was growing on the site. This impressive vegetation recovery illustrates the benefit in adopting methods which minimise peat compaction.


Aerial view showing shears-harvested area in the post-felling period (© FLS)


Ground level photograph showing site in the post-felling period (© FLS)

"Using specialised machinery driven by experienced operators allowed a challenging site to be harvested in a sensitive way. This meant that peat compaction and disturbance of existing vegetation was much lower than would have been achieved using conventional methods."

Ian McKee, Forestry and Land Scotland

FOREST TO BOG – DEMONSTRATING SUCCESS 2024

CASE STUDY E: FOULSHAW MOSS: RAISED POSSIBILITIES

Two-phase removal of established conifers from a raised bog in Cumbria

Background
In 1997 Cumbria Wildlife Trust acquired the greater part of Foulshaw Moss, a raised bog in the Lake district, from the Forestry Commission. Subsequent acquisitions enabled the Trust to take ownership of much of the peat body of this 350 ha site.

Foulshaw Moss had been afforested between the mid-1950s and mid-1960s, as an experimental site prior to the large-scale afforestation of deep peat sites in Scotland. Much of the site had been ploughed and planted with a mix of Scots pine and western hemlock. Establishment had been successful overall, with only a few small areas remaining as open space. The vegetation under the conifers was primarily Molinia caerulea.

To re-establish raised bog vegetation and a functioning peatland, the decision was taken to remove the conifers. This was done in 2 phases: the initial removal of the central area (220 ha) took place between 2001 and 2005 and the removal of the outer ring of conifers took place between 2010 and 2014. Conventional forestry techniques (forwarder and harvester teams working on brash mats and log roads) were used on both occasions.

Decision making around the method of tree removal was simple. Previous efforts to remove trees from bogs had been confined to the removal of small trees from small areas and tended to involve specialist techniques. None of these was remotely viable on a large site with 50-year-old trees and so conventional forestry was the only option. Exception was made for areas that retained favourable bog vegetation, where hand felling and sky-lining were used to minimise disturbance.

Challenges and opportunities
Following the clearance of the central area, all drains were blocked with peat dams. This led to a raising of the water table, but not to the desired levels. Removal of the outer ring of conifers enabled peat cut faces to be re-profiled and the entire peat dome to be bunded using peat to prevent water loss from the peat body.

Sphagnum cover has increased, although slowly, and has been dominated by "marsh" species, *S. palustre*, *S. fallax* and *S. fimbriatum*. This suggests an ongoing influence from nutrients deposited during the time the site was a conifer plantation.

Key successes and future ambitions
Whilst vegetation recovery has been slow, ditch blocking and bunding have resulted in rising water levels, with the water table now sitting close to the peat surface year-round. This has provided an opportunity for re-establishment of *Sphagnum*, including *S. papillosum*, *S. medium* and the rarer *S. pulchrum*. Foulshaw is now one of England's most accessible raised bogs and gets ~10,000 visitors a year, primarily attracted by the breeding ospreys. It also has a large population of the white-faced darter dragonfly, large heath butterfly, argent and sable moth and a number of other bog specialist invertebrates.

"It's been great to be involved with this project from the initial purchase through to today and to watch the bog gradually recovering from being a conifer plantation."

David Harpley, Cumbria Wildlife Trust

Removal of dense conifer plantation (© Cumbria Wildlife Trust)

Formation of pools in bunded area of the site (© Cumbria Wildlife Trust)

CASE STUDY F: RHIGOS MOUNTAINS: WORKING TOGETHER

Collaboration on forest to bog restoration allows pooling of knowledge and leveraging funding to deliver more for less

Background

The Rhigos Mountains are the most southerly mountain range in Wales, and blanket bog forms the majority habitat. They are important headwater catchments which sit above large urban areas along the south Wales coast. Many of the mountains are part of the Welsh Government Woodland Estate (WGWE), managed for commercial timber by Natural Resources Wales (NRW), including significant areas of peatlands that were planted from the 1960s onwards. Within this, the Pen y Cymoedd wind farm has been developed and is operated by Vattenfall. With 76 turbines, it is the largest operational onshore wind farm in England and Wales.

There are three ongoing peatland initiatives in the region with strong collaboration between them. These are: *Pen y Cymoedd Habitat Management Plan* (PyC HMP), a 25 year project to restore 1500 ha; *Lost Peatlands of South Wales* (LPSW) Project, a National Lottery Heritage Fund supported project which began in 2021, and the *Forest to Bog Research Project*, a Vattenfall-funded research project at Swansea University.

Challenges and opportunities

The three projects experienced challenges together and jointly agreed solutions. To combat the constraints working on an operational commercial forest and wind farm, access and permissions processes were co-ordinated. A shared resource co-ordination framework has allowed for scheduling efficiency and streamlined tendering, while ensuring works are completed to a shared best practice, working with an extremely limited contractor capacity. Alongside this, shared and joint solutions, and expertise for ecological constraints for protected and local priority species including water vole and nightjar, have been developed and agreed.

The shared delivery framework provides contractors with confidence to invest in specialist machinery for delivery which enhanced the local capacity for work, and work quality. Another opportunity has been co-located research and monitoring. Shared experimental sites with co-located equipment and sampling ensure that all data is relevant and comparable, with more evidence gaps identified and addressed than otherwise possible.

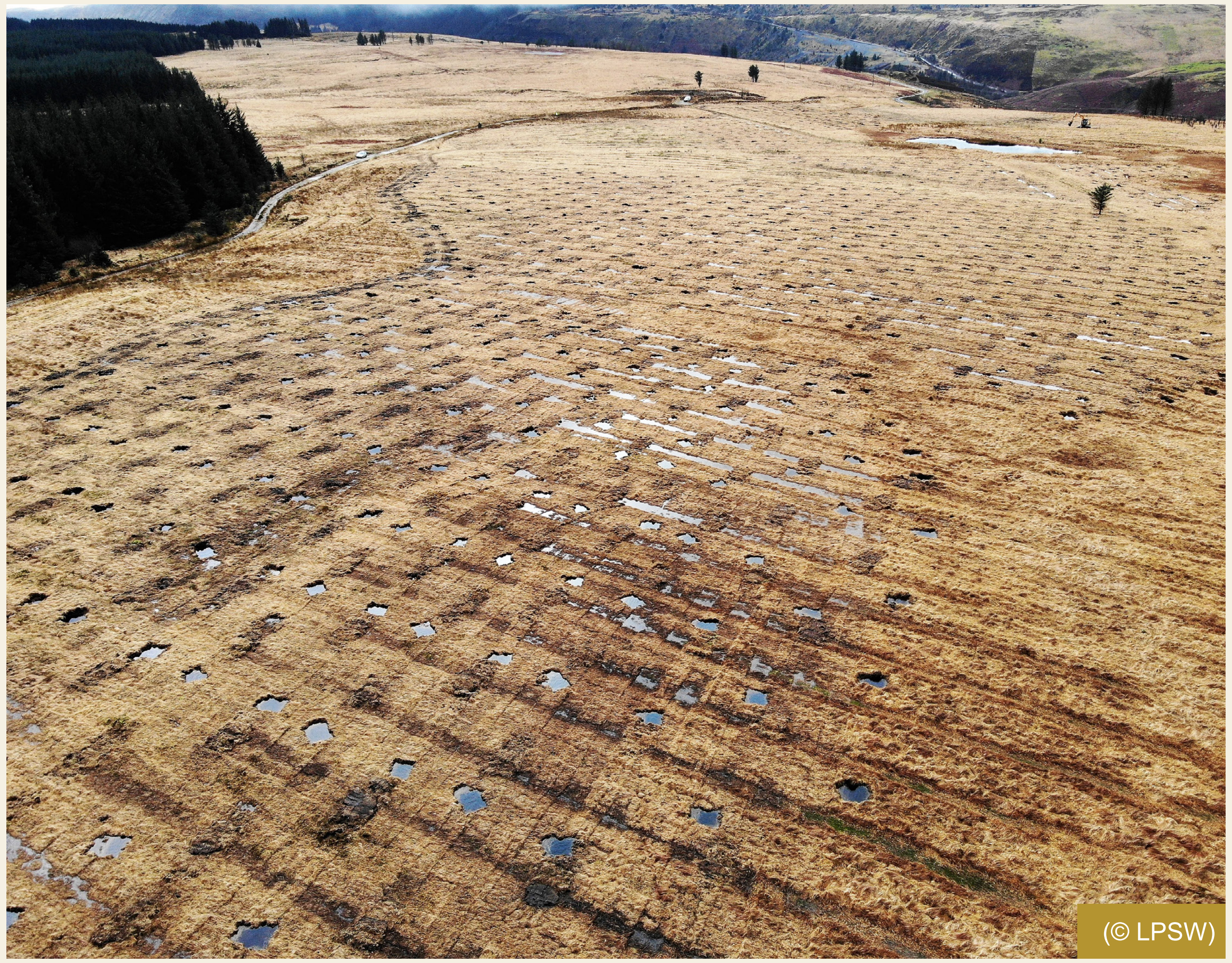
Key successes and future ambitions

The initial success was the leveraging of £1.56 million for the restoration. Community outreach was delivered, and evidence gaps around the carbon aspects were addressed. The use of ground smoothing and cross tracking has led to a more stable water table regime with characteristic bog vegetation re-establishing. Monitoring ensures interventions and techniques employed are captured, assessed, and reported on to a far more rigorous standard.

Due to the lifespan of the HMP and the rolling delivery, this can be leveraged for subsequent funding for future projects. The continued programme of research at the site and its development into a national research platform site or observatory ensure that any lessons learned are disseminated to the peatland restoration community.

Ground-smoothing operations (© LPSW)

FOREST TO BOG — DEMONSTRATING SUCCESS 2024



(© LPSW)

“The partnership approach taken to the peatland programmes in operation across the Rhigos Mountains is leading to significant investment in peatland restoration in South Wales. It is an example of a funding model for peatland restoration that is sustainable over the long term which should help the restoration programme to grow and expand – unlocking an opportunity for the area to become a real hub of peatland investment and expertise.”

Rahel Jones, Vattenfall Ltd

CASE STUDY G: MOSS OF CREE: A LANDOWNER-LED PROJECT

Landowner support is critical to both the initial success of the project, and post-restoration to achieve long-term changes

Background
Moss of Cree is an area of lowland raised bog in Dumfries and Galloway which had been afforested. After Forest Enterprise Scotland (FES) harvested the trees in 2004, Ian McCreath and his family purchased the 62-ha site in 2015 with a view to using the site for a solar array. However, when the energy market changed, he looked for other ways to use it to help tackle climate change, and decided to restore the site after a chance meeting with Peatland ACTION officer Emily Taylor.

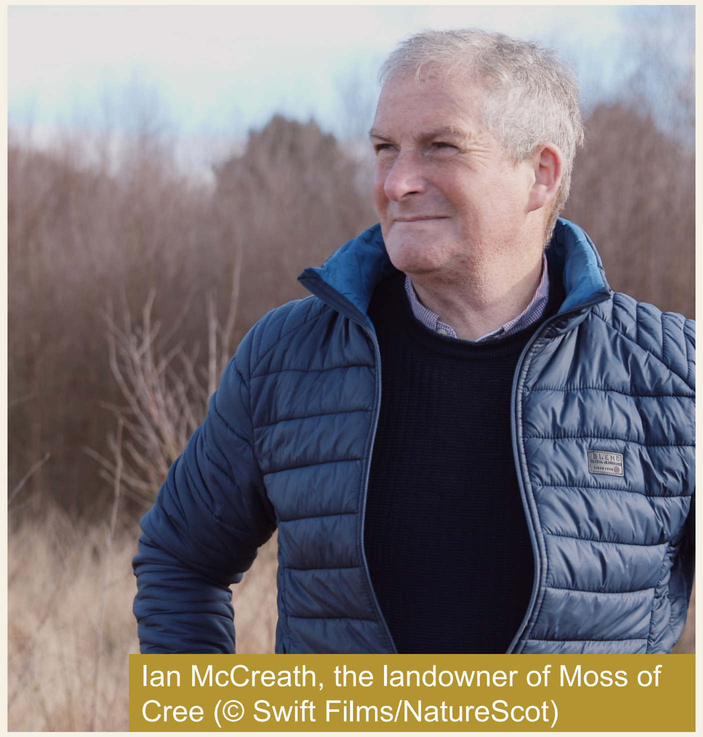
A successful funding application in 2017 led to three phases of restoration work. Peatland ACTION supported in designing the project to establish what work would be needed where and carrying out the necessary surveys. Before you can apply for funding, peat depth and hydrological surveys need to be carried out, although in the case of the Moss of Cree, peat depths had been surveyed for an earlier trial.

Ground smoothing and peat bunding were employed on the site to remove the old forestry ridges and furrows which are designed to favour tree growth and lead to lowered water tables. Low pressure excavators were used to flatten the site whilst minimising peat compaction. Peat bunding slows the loss of water to the surrounding area. The work took place in three phases, each taking approximately 4 months, over a period of 3 years.

Challenges and opportunities
As with all projects there were challenges. Ian is grappling with the regrowth of Sitka and gorse, which is currently being monitored to assess the extent of the problem so that solutions can be discussed. Previously afforested restored peatlands often require more detailed monitoring and maintenance but currently this does not fit any conventional support systems including Peatland ACTION, agri-environment schemes, or the Peatland Code.

At present the Peatland Code does not have criteria for forest to bog restoration, participation in which would be beneficial to the site. This has been a challenge which Ian hopes will be addressed in the future.

Key successes and future ambitions
Ian is keen to secure support for future monitoring and maintenance of the site. Since restoration, the water table has risen dramatically, with the right vegetation and habitat returning – and he wants to keep it that way. A recent survey identified bog specialist invertebrates, some of which are new records for the region, returning and thriving because of the success of the restoration work. Most encouragingly Ian says hen harriers, which had been in decline due to the increase in extent and density of the scrub, are now once again frequently spotted quartering the bog.


Ian McCreath, the landowner of Moss of Cree (© Swift Films/NatureScot)

FOREST TO BOG — DEMONSTRATING SUCCESS 2024

"Personally speaking, doing this restoration has been important for me. It has become a sort of legacy for the future. We feel we should do the right thing for humanity and nature, while we are stewards of this area. I would say 'do it' to any peatland owners considering restoration - it is all positive. It is the right thing to do for peatlands - they are one of the world's great carbon stores."

Ian McCreath, Landowner


Moss of Cree as it is today in the post restoration period (© Swift Films/NatureScot)

FOREST TO BOG — DEMONSTRATING SUCCESS 2024

CASE STUDY H: TYWI FOREST: FROM THEORY TO PRACTICE

Large scale implementation of different bunds and dams on a former Sitka spruce plantation

Background

The Sitka spruce plantations of the Tywi Forest were established around the 1960s. Plantations established either side of the Nant Gwinau were harvested in stages between 2006-2014. Following clear felling operations, the Forestry Commission Wales undertook some peatland restoration on the peatland to the south of the Nant Gwinau (between 2006-2009). These works included the blocking of a gully with large peat dams and the construction of several ponds fed by former forestry drainage channels.

The National Peatland Action Programme (NPAP) came into being in September 2020, funded by Welsh Government and managed by Natural Resources Wales. In March 2021 and 2022, the peatlands north and south of the stream were managed to prevent conifer regeneration and broadleaved regeneration through felling conifers to waste, stem injection of broadleaved species and mulching of regenerating conifers. The peat on the site is up to 4 m deep. During February and March 2023, a groundworks phase of restoration was delivered using several restoration techniques, some of which had not yet been carried out by the NPAP staff on an afforested site.

Works to the south of the Nant Gwinau (covering an area of ~14.4 ha) involved construction of contour bunds across areas of previous ridge and furrow, low peat dams typically in low lying flushed areas, large peat dams in gullies and standard peat dams in previous forestry collector drains. Works to the north of the Nant Gwinau (covering an area of ~7.9 ha) involved construction of contour bunds on deep peat (>80 cm) and within areas of shallower peat (roughly 40-50 cm), low peat dams in a low lying valley bottom, standard peat dams in previous forestry collector drains, and ground smoothing techniques including 'stump flipping with surface smoothing', 'stump wind-rowing with surface smoothing' and 'wave damming'.

Challenges and opportunities

NPAP practitioners strived to ensure that all structures were constructed out of amorphous peat that is resistant to water movements. The reality is that factors such as the varying peat depths, condition of the peat, amount of brash and woody debris all have an impact on what can and cannot be built, how free the structures are of material other than peat, and how well the structures will ultimately fare in the long term. In shallower peaty areas it was difficult to avoid exposing the bedrock despite consideration and effort to ensure that all structures were built into the existing peat profile or at worst the underlying clay seal (with a particular focus on not rupturing it).

Key successes and future ambitions

Over the course of this groundworks phase NPAP delivered:

- 8,273 m of contour bunds
- 1,004 m of low peat dams
- 9 large peat dams
- 623 standard peat dams
- 4.06 ha of ground smoothing

It has been an extremely useful exercise in understanding the successes and failures of different methods on sites with a shallower degraded peat profile.

Nant Gwinau in the pre-restoration phase, conifers are planted on ridges and furrows (© Wales NPAP)

Nant Gwinau in the post-restoration period showing contour bunding across the ridges and furrows (© Wales NPAP)

"Nothing worth doing is easy! The sites looked a lot wetter at the end of the contract which was a huge positive. Our hope is that this was not just a result of March being incredibly wet and that water levels will remain high across the sites during the summer."

Robert Bacon, National Peatland Action Programme

CASE STUDY I: PORTMOAK MOSS: A COMMUNITY LED EFFORT

A Woodland Trust Scotland project, in conjunction with the local community

Background
Portmoak Moss, in the village of Scotlandwell, Kinross-shire, is a lowland raised peat bog. It is owned by the Woodland Trust Scotland and managed by them in conjunction with the Portmoak Community Woodland Group. Over many years, the land was cut for fuel, drained, and converted for agriculture, resulting in only a small area of the bog remaining by 1960. Subsequently, it was sold to the Forestry Commission and turned into a commercial plantation.

In 1996, it came up for purchase and a community-led effort to raise funds helped the Woodland Trust Scotland to buy it. By this time, the woods were a monoculture and the bog beneath was presumed to have been lost. However, the Woodland Trust Site manager had expertise in peatlands and assessment showed that the peat had a depth in the central area of ~6 m with depths of 2-3 m on the surrounding areas. Several species of *Sphagnum* were also identified.

The commercial conifers covering the peat dome were cut down and removed by high lining. Ditches were dammed, to raise the water table and reduce run off. The uneven surface, with birch colonising the higher humps, was levelled by mulching. This was followed by contracts for birch control.

Challenges and opportunities
The biggest challenges came in the form of communication with the local community. The area had been well used for recreation whilst it was wooded, and in the post-felling period the site was devastated. Strong networks built by the Community Woodland Group were vital in gaining support from the wider community. As people came to meetings, read articles, and engaged with the work, they came to appreciate the importance of the project, cementing support for the long-term restoration.

As birch began to regenerate around the edge, it was cut back, and the stumps treated with weedkiller. This was quick to do but it was hard to halt the spread of birch and repeat treatment has been needed every couple of years. Meanwhile, Woodland Group members have been pulling birch by hand.

There has been a tool set up called 'Let's Talk Bogs' based on Portmoak Moss, which can be used by primary school teachers to lead discussion on all aspects of peat bogs, providing the opportunity to inspire the next generation of conservationists.

Key successes and future ambitions
The Portmoak Community Woodland Group have organised many different public events to highlight the history and biodiversity of the Moss - fungal forays, dawn choruses, damsel and dragonfly walks, and moth and *Sphagnum* identification. Woodland Trust Scotland also organised a lantern festival and a popular annual event is Christmas tree day, where people take away regenerating Sitka spruce, which helps the bog.

The dense canopy and thick carpet of fallen pine needles meant there was little in the way of flora or birds and minimal insects or other animals (© Jeff Gunnell)

Area of restored peatland showing difference between birch which has been cut and poisoned (left) and birch which has been manually pulled (right), which stays clear for several years (© Jeff Gunnell)

> *"My husband and I signed up for Woodland Trust membership last year and we so appreciate all the work you volunteers do in 'the Moss', especially taking out the self-seeded birch and other trees - which threaten its continued existence. To us it is a magical place and each time we walk we see and enjoy something different."*
>
> Anne Taylor, artist

FOREST TO BOG — DEMONSTRATING SUCCESS 2024

CASE STUDY J: SCOTTISHPOWER RENEWABLES: LARGE SCALE RESTORATION

A long term research and restoration project on a Scottish windfarm

Background
After trialling the peatland restoration methods with the most potential, ScottishPower Renewables (SPR) began work at landscape-scale in 2014 at Black Law Windfarm. Now, 2,661 ha of peatland has been restored across six windfarms with £1.1 million spent on peatland research over the last 15 years.

Challenges and opportunities
Quickly recovering vegetation is a positive indicator for successful restoration, but other monitored features take longer to stabilise. The water table is closer to the surface than pre-treatment (generally within 20 cm even during drought periods), although the number of monitoring points with a water table that remains within 10 cm of the peat surface during drought periods is much lower. It might be that more time is needed for the water table to be consistently within the top 10 cm of peat or possibly that the historic damage to some of these sites is so high that they will never fully recover to a pristine condition.

On previously planted sites methods such as ground smoothing are generally effective in removing regenerating non-native conifers, but removal of remaining trees is still required within untreated areas such as buffer strips (untreated strips to catch run-off and provide refuge for animals and plants) to prevent establishment.

The presence of thick-branched *Sphagnum* spp. has also been slow to establish, but as these species are linked to wetter conditions, their presence is likely to mirror a water table that is closer to the surface of the peat, and with this the chance for the growth of characteristic microtopographic structures.

Key successes and future ambitions
Monitoring data suggests that typical bog plants are quick to recolonise. Desirable species such as *Eriophorum* spp. recover quickly in the first three years after treatment, before stabilising after 4-5 years. *Sphagnum* mosses, one of the most important components of bog vegetation, reached 25% cover 2 years after treatment, including the large peat-building species. The water table is measured in drought conditions, i.e., the worst-case scenario, meaning a higher water table is assumed for much of the year. Despite several years of variable and unseasonable weather, the water table sits within 20 cm of the surface at most sampling points.

The first decade of monitoring has shown the quick colonisation of vegetation and a reduced distance between the water table and the peat surface, but longer-term monitoring is required to detect other or continued positive trends, such as a continued rise of the water table to the surface, amongst the variable nature of the current climate. Future data will help to prove whether the works undertaken have restored the long-term natural processes required to achieve self-sustaining habitats so that the current restoration methods can be used with the confidence of long-term success.

Area of restored peatland showing extensive colonisation by *Eriophorum vaginatum* and pools with *Sphagnum* growth at the edges (© ScottishPower Renewables)

An area of forest to bog restoration (© ScottishPower Renewables)

“Substantial areas of peatland restoration have been committed through the planning mechanism for renewable energy developments in Scotland. ScottishPower Renewables has been investigating the most effective and environmentally sensitive methods of peatland restoration for the last decade. Monitoring data indicates that such methods have helped to re-establish historic hydrological regimes and key vegetation indicator species. However, further monitoring is required to determine long-term trends.”

Glenn Norris, ScottishPower Renewables

FOREST TO BOG — DEMONSTRATING SUCCESS 2024

CASE STUDY K: TULLYCHURRY: RESTORATION TO TRIAL NEW TECHNIQUES TO IMPROVE RAW WATER QUALITY

A case study looking at the impacts of forest to bog restoration on potable water supplies in Northen Ireland

Background
There are areas of conifers planted on deep peat in several NI Water source drinking water catchments. The EU INTERREG VA Source to Tap project provided the opportunity to trial two techniques, which if successful, could then be used in other drinking water catchments.

Forest Service (DAERA) offered a formerly afforested 30 hectare site at Tullychurry Forest, County Fermanagh which was not being replanted and which was adjacent to an internationally designated area. With a peat depth generally greater than 1 m and a slope of less than 3 degrees on some areas of the site, it presented an opportunity to trial the cell bunding technique, which is the construction of watertight cells from low peat walls.

Challenges and opportunities
Following topographic and ground truthing surveys, 145 cell bunds were constructed. The operators were experienced in working on soft ground and on brash mats. To ensure watertight cell bunds, a trench was dug for the walls to be built. It was important to avoid or remove tree stumps and to not dig so deep as to hit mineral layers, as either could cause future leaks. The bund walls had to be high enough to raise the water table by approximately 10 cm above the base of the cell but not exceed 40-50 cm, or the pooled water would be too deep for *Sphagnum* to thrive and higher volumes of water within the cells could cause the bund walls to breach. Once constructed, the bunds quickly filled with water so if *Sphagnum* seeding was planned, it must be done immediately following construction.

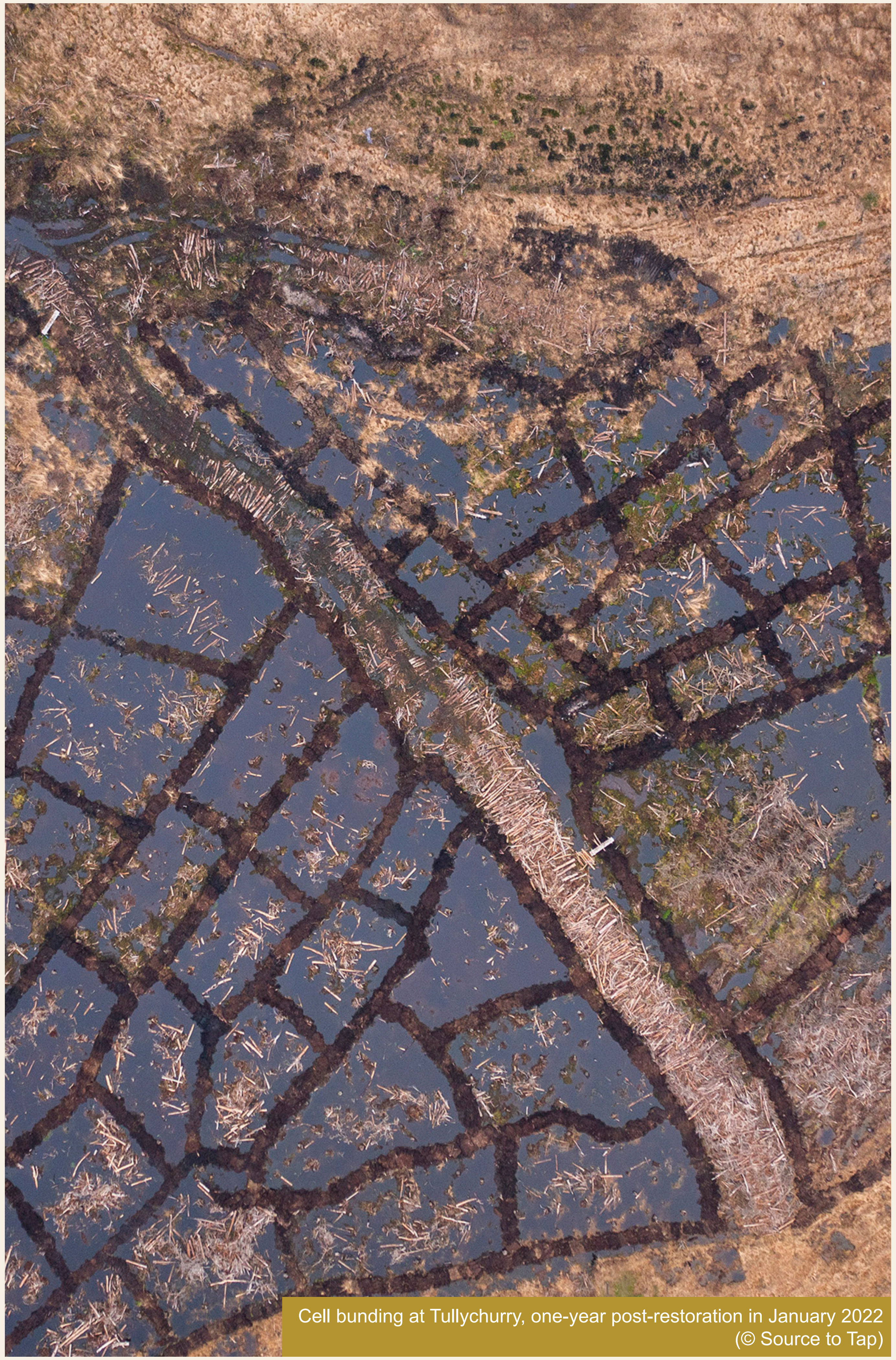
Over steeper areas of the site, drains and brash mats were blocked with peat dams at 12 m intervals or every 30 cm drop in ground level.

Key successes and future ambitions
Cell bunding was shown as a viable technique for formerly afforested deep peat on flat terrain and was next used adjacent to a drinking water reservoir. The 27 ha site at Lough Bradan in County Tyrone had 221 cells constructed on the flatter western shores, with the drains on steeper areas of the southern, northern, and eastern sides blocked with peat dams. *Sphagnum* mosses quickly started to re-establish, slowing the flow, and filtering the water before it enters the Lough to be abstracted for water treatment. Erosion across the top of the cell bunds, caused by over-topping, means that in future cell bunds will be constructed with water outlets to provide a defined path to reduce erosion.

Twenty dip wells were sunk across the Tullychurry site, but these provided too few data points over just the one sampling season to give sufficient statistical certainty. Therefore, the number of dip wells will be doubled in future which will increase spatial resolution and hopefully lead to insights into the correlation between water table recovery and colour.

"The Tullychurry Forest peat restoration pilot provided the opportunity to trial cell bunding on a site previously planted with lodgepole pine. It was amazing to see how quickly the site became wetter and Sphagnum recolonized, and to share the learnings with a range of stakeholders, as well as to implement them adjacent to a drinking water reservoir."

Diane Foster, NI Water Source to Tap Project Manager
www.sourcetotap.eu



Cell bunding at Tullychurry, one-year post-restoration in January 2022 (© Source to Tap)

CASE STUDY L: FORSINARD: INSIGHTS FROM BRITAIN'S MOST EXPANSIVE PEATLANDS

Two decades of research from the UK's largest peatland evidence impact and provides management improvements

Background

The RSPB Forsinard Flows National Nature Reserve (NNR) and surrounding areas in the Flows of Caithness and Sutherland have hosted many research projects, with RSPB acting as both land managers and science partners. As well as research undertaken by RSPB, the James Hutton Institute have conducted research within the Forsinard NNR since 2006, ranging from Scottish Government-funded 5 year research programmes to NERC and EU funded initiatives.

Since 2012, research has also been facilitated by the Flow Country Research Hub, a network of >60 stakeholders coordinated by University of Highlands and Islands North, West, and Hebrides' Environmental Research Institute (ERI). The research has built a compelling evidence base documenting both the impacts of forestry, and the trajectories of forest-to-bog restoration sites following a wide range of management interventions.

Challenges and opportunities

Whilst the field centre and team have supported many research organisations, significant challenges remain to delivering applied research at Forsinard. For instance, short-term grants and projects make it difficult to ensure the continuity needed for ongoing maintenance and replacement of equipment aiming to capture long-term processes – such as flux towers and water table loggers. This challenge is heightened when working in a remote, isolated, cold, wet, and windy environment, where equipment failure is common. This continuity of funding also poses challenges for the retention of high-skilled and specialist staff who support the data collection and analyses.

On the other hand, the length of the research and the richness of the datasets from Forsinard make it a unique station in the UK, as it provides great opportunities to deepen our understanding of longer-term impacts of land management intervention.

Key successes and future ambitions

Research has provided the first empirical evidence of climate benefits of forest-to-bog restoration as well as long-term effects of forestry on carbon stocks. James Hutton Institute data analysis feeds into annual reassessments of the UK GHG (greenhouse gas) Inventory peatland sector reporting and revisions of the UK Peatland Code. Continued work in this field is likely to support nature conservation by enabling effective carbon accounting of a range of peatland restoration activities.

Research on water quality and hydrology in forest-to-bog catchments and freshwater streams and rivers has clearly demonstrated short-term and short-lived impacts of intervention that can be mitigated by appropriate management techniques. In addition, so-called "legacy effects" of forestry have been documented for a range of ecohydrological properties. These findings have contributed to support the rationale for further management interventions on forest-to-bog sites.

Ongoing research on a diverse range of remote-sensing techniques will support conservation by rapidly and cost-effectively assessing peatland restoration outcomes and supporting adaptive management. Forsinard Flows reserve, has proven to be an exceptional "laboratory" or "observatory" of peatland restoration, where land managers and scientists work together in long-term collaborations, to better understand outcomes and improve management approaches.

"Forsinard, in the heart of the Flow Country, is a fantastic natural laboratory where research has been allowed to grow alongside and inform restoration practice over more than two decades. All those involved in this research can be proud to be supporting a globally important blanket bog and informing national policy."

Roxane Andersen, Environmental Research Institute

Vegetation surveys following *Sphagnum* translocation at the Dyke forest-to-bog restoration sites, Forsinard (© Roxanne Andersen)

FOREST TO BOG — DEMONSTRATING SUCCESS 2024

CASE STUDY M: CORS-Y-SARNAU: FROM THEORY TO PRACTICE

Using digital surface modelling to identify hydrological and topographical barriers to successful restoration

Background
The site has a variety of wetland habitats on deep peat deposits. The peatland extends into an adjacent conifer plantation (Coed Tŷ Uchaf), where remnant mire communities are still present. Coed Tŷ Uchaf was acquired in 2014 with view to restoring the wetland habitats. Conifers were removed in 2016, revealing a complex network of ditches, grips and forestry furrows. Larger ditches were partially blocked with brash, with limited success; the central areas, particularly ridges where trees had been planted, were drying out and dense birch regeneration rapidly took place. In 2020, through the Interreg NWE Care-Peat project and with support from Natural Resources Wales, a hydrological restoration plan was created to re-wet the deeper areas of peat by targeted damming of the ditches. A lack of baseline data, and the legacy of forestry operations leaving a landscape which was both uneven and dotted with tree stumps created unique challenges.

Challenges and opportunities
Hydrological surveys concluded that water loss from the bog was mainly through groundwater seepage or hidden/buried ditches, driven by a large hydrostatic gradient between the top of the peat domes and the adjacent stream. Therefore, damming individual ditches was unlikely to have significant impact on flow rates and the high hydrostatic gradient.

An alternative solution was needed to tackle the irregular ditch spacing and groundwater flow. A low-profile contour bund has been created along the lower edge of the main restoration area; a technique more commonly used in upland settings to slow water flow over bare peat. The bund has created a continuous flow barrier which removes any cracks, root zones or hidden ditches that allows water groundwater to bypass dams. The bund is raised slightly above the current surface of the bog, increasing the volume of rainwater that can be stored.

Key successes and future ambitions
Initial monitoring found groundwater levels within the central part of the restoration area had risen slightly and were stabilising at higher levels compared to pre-intervention levels. The bund continues to raise groundwater levels in areas beyond its physical limits on the surface.

Direct observations of the bund have shown that it is functioning well, increasing volume and duration of water retention. Water is pooling to the top of the bund in many places (~20 cm above the existing bog surface) following periods of heavy rainfall, and surface water is pooling back up along the ditches and spreading onto low-lying areas of the bog.

Ongoing monitoring of groundwater levels will improve understanding of compartmentalisation of groundwater within the restoration area and identify areas where further bunding or ditch blocking would be beneficial.

Surface water held behind a section of bund at Cors-y-Sarnau (© North Wales Wildlife Trust)

The bog surface following scrub clearance in February 2022 (© North Wales Wildlife Trust

"When we realised how complex the restoration area was, there was a real temptation to level the surface and start from scratch. This certainly would have been the quickest way to rewet it, but then we would have lost all the amazing wetland plants that have been hanging on below the conifers for so many years, which would have been a real shame. So, in the end we chose lower-impact restoration methods rather than rushing in and trying to fix everything at once."

Richard Cutts, North Wales Wildlife Trust

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www.npt.gov.uk/21233, www.swansea.ac.uk and group.vattenfall.com/uk

Marches Mosses, BogLIFE
themeresandmosses.co.uk

National Peatland Action Programme
naturalresources.wales/evidence-and-data/maps/the-national-peatland-action-programme

Northern Ireland Water
www.niwater.com

North Wales Wildlife Trust
www.northwaleswildlifetrust.org.uk

Peatland ACTION
www.nature.scot/climate-change/nature-based-solutions/peatland-action

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