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The future of peatland forestry in Scotland: balancing economics, carbon and biodiversity

Summary

From the 1940s to the 1980s large areas of conifer forest were planted on Scottish peatland. Many of these plantations are now reaching harvesting age and critical questions surround what should be done with them next. This paper reviews and summarises some key issues, outstanding questions and ongoing research in this area. Three key options for the future are: re-stocking plantations for a second rotation; restoration of plantations to open bog; and a 'middle-way' option which attempts to retain trees but without the negative consequences of commercial forestry. Each of these options faces practical issues and difficult trade-offs between the economic value of forestry, biodiversity, and the value of peat as a store of carbon which mitigates climate change. The future of peatland forestry in Scotland is likely to be a patchwork of each of these possibilities. Decisions on which option is right for which site need to be made soon but doing so will be difficult given large gaps in the underlying science.

1. The importance of peatlands

Peatlands are a comparatively rare habitat, covering only around 3% of the globe, but are disproportionately important in many ways (Dise, 2009). Much current interest is driven by the fact that peat is rich in carbon (~50% of solid matter)(Lindsay *et al*, 2010) and global peatlands store an estimated 600 gigatons of carbon (GtC) (Yu *et al*, 2010). To put this in context, the Intergovernmental Panel on Climate Change estimate that prior to human carbon dioxide emissions, the carbon content of the entire atmosphere was a similar 589GtC (Stocker, 2014). Comparing these two numbers, it is clear that changes in the peatland carbon pool have the potential to significantly affect global climate. While intact peatlands store carbon in a largely inert form there is concern that degrading peatlands may be significantly exacerbating anthropogenic climate change through release of carbon dioxide (Hooijer *et al*, 2010). This concern is currently motivating extensive attempts to conserve and restore peatlands around the world; however, carbon is not the only reason to value peatlands. Peatlands also play important roles in water quality and supply, host a range of unique species, provide spaces for recreation and preserve a record of past environments and human activity (Bain *et al*, 2011). Forestry is often considered a threat to many of these 'ecosystem services'.

2. Scottish peatlands and forestry

Scotland is a singularly peat-covered country. Different definitions and data sources mean that estimates of Scottish peat cover vary, but may account for up

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Figure 1: Peatland ploughing for afforestation. In this 1979 image, a low ground-pressure tractor is towing a double mould board plough at Rumster Forest, Caithness. Photograph by George Dey, presented by permission from the University of Aberdeen and courtesy of Norman Davidson and http://www.forestry-memories.org.uk.

to 30% of the total land area (Chapman *et al*, 2009), a higher proportion than almost any country in Europe (Montanarella *et al*, 2006). The largest extents of peat occur in the north and west, particularly the Flow Country of Caithness and Sutherland, the Isle of Lewis, and Dumfries and Galloway (Chapman *et al*, 2009). This peatland has traditionally been viewed by some as low-value wasteland, often used only for deer stalking, or low-density sheep grazing.

For more than a century, Scottish peatland has attracted the interest of foresters as a potential location for new forestry. To quote an early twentieth century forester: "There is a special fascination in coaxing useful plantations to arise 'in the wide desert where no life is found'" (MacDonald, 1945). While attempts to afforest Scottish peatlands go back to the 18th century, they were limited in extent and success before the mid-20th century. Following the Second World War, the introduction of new tree species, advent of better tractors and the Cuthbertson double mouldboard plough led to the first large-scale plantations by the Forestry Commission (MacDonald, 1957) (**Figure 1**). While afforesting peatland remained a considerable challenge (**Figure 2**), it was increasingly technically feasible to plant trees on peat. Later but equally important in promoting peatland forestry was a generous tax incentive system which made afforestation financially very profitable for private companies and individuals (Stroud *et al*, 2015; Warren, 2000). At a governmental level, forestry on peat was viewed as a means to encourage employment in remote areas, reduce dependence on timber imports and make 'wasteland' productive. By the mid-1980s, perhaps more than a tenth of UK peat had been planted with conifers, mostly the North American imports Sitka spruce (*Picea sitchensis*) and Lodgepole pine (*Pinus contorta*). However, from the late 1970s, there was an increasing conservation backlash focused particularly on the Flow Country and the impact of afforestation on the wildlife and landscape of an area often viewed as Scotland's last wilderness (Stroud *et al*, 1988; Warren, 2000). Amidst considerable acrimony, new peatland afforestation mostly ceased by the end of the 1980s (Stroud *et al*, 2015). Contributory factors to this cessation of new planting included the removal of tax incentives in 1988, the conservation designation of large areas of peat, and ultimately Forestry Commission guidance against new planting on deep peat (Patterson and Anderson, 2000). While planting trees on peat was technically possible, producing useful timber from peatland plantations has not always proved easy. Tree growth has often been slow, particularly in wet sites or where drains have not been maintained (Tittensor, 2016). Lodgepole pine planting has often produced trees with crooked trunks ('basal sweep'), impairing timber quality. On deep peat, many plantations have been subject to wind-throw and plantations have also faced problems with pests and diseases such as the Pine Beauty Moth and Dothistroma needle blight (Warren, 2000).

Figure 2: The difficulties of peatland afforestation. In this 1983 image a tractor and plough (the same vehicle as Figure 1) has become bogged down in deep peat at Benmore in Shin Forest, Sutherland. Photograph courtesy of Norman Davidson and http://www.forestry-memories.org.uk.

3. Peatland forestry and carbon

The change in attitudes to peatland forestry at the end of the 20th century was primarily driven by increasing concerns about impacts on wildlife, but today much current interest is driven by questions about the impacts of peatland forestry on climate. In many global contexts afforestation is viewed as an effective climate mitigation strategy due to carbon sequestration by the trees, but this may not be the case in UK peatlands. Milne and Brown (1997) estimate the carbon stock of all British woodlands to be around 100 megatons (Mt), but the carbon stock of Scottish peatlands to be 4523Mt. While there are large uncertainties associated with these numbers it is unambiguous that Scottish peatlands store far more carbon than Scottish woodlands. There is conflicting evidence on whether planting trees on peat leads to more carbon loss from peat than is gained by the trees.

In tropical and boreal regions, naturally forested peatland is common, but most Scottish peatland is currently treeless with the exception of recent plantations. While there are a few locations, mostly in the Eastern Highlands, with seemingly natural occurrence of native trees on peat, these are rare, perhaps because most of Scotland has a less continental climate, a history of continuous high herbivore pressure and in many areas a lack of seed source on and around peatlands (Anderson and Harding, 2002; MacKenzie and Worrell, 1995). The widespread presence of pine stumps in peat (Birks, 1975) demonstrates that there may have been more widespread naturally forested peatland earlier in the Holocene, but today the natural state of almost all Scottish bogs is treeless, with surface moisture too high and nutrient levels too low for trees to prosper. For conifers to grow on peat these constraints must be removed, so tree planting is preceded by the digging of drainage ditches and ploughing to provide raised, competition-free planting positions and application of fertiliser (phosphorous and where required potassium and nitrogen) to increase nutrient availability (Taylor, 1991). These are conditions which we know are likely to lead to oxidative loss of carbon from peat. Lowering the water table exposes a greater depth of peat to aerobic decomposition and tree roots and peat cracks allow air to penetrate the peat (Hargreaves et al, 2003). Carbon losses during the process of planting are likely to be large with erosion of particulate carbon from exposed peat surfaces, decomposition of dead plant material and newly-exposed peat, and more rapid flushing of organic carbon through the ditch network (Trettin *et al*, 1996). Fertilisation is likely to promote microbial activity and conifer root exudates may 'prime' the loss of old carbon from the peat (Basiliko *et al*, 2012). Impacts on the bog may accelerate as the canopy closes after 10-15 years. This increases interception and evapotranspiration and effectively excludes primary production by any remaining bog vegetation (Anderson *et al*, 2000).

> **"Trees are likely to have much greater primary production than natural bog vegetation and, unlike an intact bog, a drained bog is likely to produce little methane"**

It is widely acknowledged that afforestation has the potential to lead to carbon loss from the peat store, but how much carbon may be lost and how this varies, remains almost entirely unknown. The issue is not straightforward, as carbon lost from the peat and the original vegetation, may be balanced by atmospheric carbon fixed by the trees. Trees are likely to have much greater primary production than natural bog vegetation and, unlike an intact bog, a drained bog is likely to produce little methane. The ultimate carbon balance depends on the long-term fate of harvested timber (Hargreaves *et al*, 2003) and the amount of carbon incorporated into the peat via needle litter, root litter and root exudates (Vanguelova *et al*, 2017). The carbon storage implication if wood products from peatland plantations are utilised for long lifespan products (e.g. in construction) may be quite different to that if wood is used for short lifespan uses (e.g. fuel) or left to rot in-situ. The implication of afforestation for carbon balance is therefore the difference between the carbon lost from the peat and the original vegetation and the carbon retained in trees and tree products over the time period under consideration. Neither side of this equation is well-constrained and considerable current research is investigating this issue.

Studies of the impact of forestry on peatland carbon fall into two general categories: studies investigating carbon fluxes and studies investigating carbon stocks. The former are more numerous and focus on quantifying the movement of carbon in and out of peatlands as carbon dioxide, methane and aquatic carbon. This is an active research area with projects ongoing at many Scottish universities, Forest Research, the James Hutton Institute (JHI) and the Centre for Ecology and Hydrology (CEH). The key advantage of this approach is that it allows different forms of carbon, with differing climate warming potential, to be disaggregated and the underlying mechanisms to be probed. The key disadvantage is that the flux approach can only investigate the situation as it currently stands. This is significant because large quantities of carbon were probably lost from peatlands during ground preparation and the early stages of planting, but it is now impossible to quantify these fluxes because peatlands are no longer being newly afforested (Hommeltenberg *et al*, 2014). It is for this reason that an approach based on carbon stocks is also valuable. In this approach the total quantity of carbon is calculated and compared between peatlands with and without forestry, results thereby account for all loses and gains of carbon over time. The key difficulty in studies of this nature is ensuring comparability of values, particularly as peat carbon stock can be very spatially variable. In our current research we are using volcanic ash ('tephra') layers as unambiguous age-markers in peat cores to make quantitative comparisons between peat segments in forested and unafforested Scottish peatlands (see https://www.york.ac.uk/environment/carbon-accumulation-loss/).

4. Peatland forestry and biodiversity

Beyond their value as a carbon store, peatlands contain a huge diversity of organisms, from microscopic testate amoebae to the UK's largest land mammal, red deer. While the absolute numbers of these plant and animal

Figure 3: The current state of peatland forestry (RSPB Forsinard in 2014). In the foreground trees have been felled-to-waste as part of peatland restoration while in the background the plantation remains standing.

species are often low, many are species specially adapted to wet and acidic conditions and therefore only found in this habitat. Planting trees on peat leads to a fundamental change in the ecosystem. The tree canopy shades out other plants and drying of the peat surface and nutrient addition change the very characteristics of the ecosystem which peatland organisms are adapted to. Consequently, the plant and animal communities found in afforested peatland are very different to those of natural, open, peatland (Stroud *et al*, 1988). Planted sites typically include a greater abundance of generalist and woodland species and far fewer peatland specialists. This is most immediately apparent in the plants: open peatlands typically have extensive carpets of *Sphagnum* mosses, sedges and shrubs; whereas afforested peatlands typically have large areas of needle-covered bare peat, brown mosses and *Sphagnum* is often entirely restricted to wet ditches (Stroud *et al*, 1988). The loss of *Sphagnum* with afforestation is particularly significant as these mosses are often considered to be 'ecosystem engineers', due to their roles in acidifying and slowing decomposition in peatlands (van Breemen, 1995). The effects of peatland afforestation on biodiversity may extend well beyond the plantation itself through the effects of forestry on surrounding unplanted peatland and the influence of trees and infrastructure on movement patterns of larger animals. For some birds, including dunlin and golden plover, this 'edge effect' extends hundreds of metres beyond the plantation itself (Wilson *et al*, 2014). Current research is investigating the impacts of forestry on peatland birds (RSPB), insects (University of the Highlands and Islands and JHI), plants (several universities) and microorganisms (Edge Hill University).

5. The future of peatland forestry

In light of the potential impacts of forestry on peatland carbon and biodiversity it is unlikely that Scotland will see extensive new tree planting on peat in the medium-term future. The fate of existing plantations is less clear. Current forestry policy recommends three alternative options: restocking, restoration and a 'third way' termed 'Peatland Edge Woodland'; the future is likely to see a mosaic of all three (Forestry Commission Scotland, 2015, 2016) (**Figure 3**).

i) Re-stocking.
Where tree growth has been good and timber has economic value, peatland plantations are likely to be restocked, often as like-for-like replacement. Forestry Commission guidance proposes that restocking is likely to be the preferred option where good growth is possible under current site conditions using minimal cultivation and fertiliser addition (Forestry Commission Scotland, 2015). Extensive restocking is already under way in locations where tree growth has been good in the first rotation, particularly in drier sites and on shallower peat. The Forestry Commission guidance acknowledges the potential for forestry to lead to peat carbon loss, but operates on the basis that this will be compensated for by carbon fixed during tree growth, where this is strong (for Sitka spruce, a General Yield Class greater than 8). This assumption is open to question given the currently limited and uncertain science in this area (Forestry Research, 2014).

ii) Restoration.
In other locations, restoration is likely to be the preferred option. Since the potential problems of peatland afforestation were first recognised various organisations have been studying how to restore afforested peatlands towards their natural 'open' state (Andersen *et al*, 2017; Anderson and Peace, 2017). There are now ambitious national targets for peatland restoration and extensive investments are being made by government (for instance through the Scottish Rural Development Programme and SNH's Peatland Action programme) and NGOs (RSPB, Scottish Wildlife Trust etc.), along with efforts to leverage private investment through the Peatland Code (Reed *et al*, 2013). Restoring afforested peatland is not simple, due to the multiple ways in which tree planting modifies the peatland environment. Most forest-to-bog peatland restoration in the UK focuses on two key interventions: removing trees and raising the water table. Trees have been either felled to waste and left on site (**Figure 4**) or, increasingly, harvested and removed from site. The latter is recognised as the preferred option, but has not always been viable because restoration is often undertaken before the trees reach a size where harvesting is financially viable. On some deep peat sites, trees grow so slowly that they will only ever produce low-value timber, which it is not economic to harvest. Where trees remain on site after felling, they are often placed in the drains and plough furrows to slow drainage and reduce decomposition rates. There is current interest in the possibility of actively burying wood in

Figure 4: Forest-to-bog peatland restoration underway at RSPB Forsinard. In this 2014 image the digger is conducting secondary treatment, compacting previously felled-to-waste trees into the plough furrows.

the peat to retain the wood carbon in the peat for the long-term (Zeng, 2008).

In parallel with tree felling, restoration projects aim to raise the water table to prevent peat oxidation and restore the conditions required by typical peatland plants. This is usually achieved by blocking ditches and furrows usually with dams constructed of compressed peat (or occasionally with plastic piling) (Anderson and Peace, 2017). In some newer restoration projects, this ditch-blocking is combined with re-profiling involving flattening of plough ridges and infilling of furrows to give a flatter, wetter surface more similar to that of a natural bog. In other, typically drier sites, restoration organisations have experimented with more intensive hydrological interventions such as 'cell bunding', in which trenches filled with packed peat are used to create a network of bunds which form cells to retain water. Similarly, organisations have experimented with 'contour bunding', where bunds follow the topography; current Forestry Commission trials of this approach have proved promising.

Restoration is a long-term process and even sites restored many decades ago remain considerably different from natural peatlands. For most sites the assumption is that once trees are removed and water table raised the plant community will eventually progress towards a community typical of open bog and as this happens other species will also return. However, recovery may be slowed by forestry legacy, such as the release of nutrients from brash and needle litter years after the trees have been removed (Gaffney, 2017). In some sites, certain non-target species can become dominant during restoration (e.g. *Molinia caerulea*) and may inhibit the recovery of many typical bog species. In some restoration projects, experiments have been made to speed vegetation recovery through translocation of plants and application of micropropagated plant products in an effort to restore cover of typical species, particularly *Sphagnum* mosses (Rosenburgh, 2015). Restoration is an ongoing process and practice has developed through a process of trial and error. As complete forest-to-bog restoration is expected to take many decades, the trajectories of restored sites are uncertain. Experience thus far suggests that restoration cannot always be viewed as a 'one off' intervention, but rather initial tree-removal and ditch blocking may be the start of a long-term process requiring multiple interventions as restoration progresses and restoration practice improves (**Figure 4**). On many forest-to-bog restoration sites, especially those where some trees remain, or where the peat surface remains relatively dry, natural regeneration of both non-native crop species and native tree species (especially birch) will be an ongoing management issue and may require repeated active management through felling, herbicide treatment, or pulling of seedlings. Although much research is focused on the consequences of restoration, the development of restoration methods has largely emerged through an informal process of experimentation by practitioners, combined with attempts to learn from each other's experience. There is little doubt that in the long-term, restoration is likely to yield benefits in terms of carbon storage and biodiversity, but this comes at a cost of the economic value of the forestry removed (albeit often small) and the substantial cost of restoration itself.

There are currently key socio-economic questions outstanding, as attempts to assess the costs and benefits of forest-to-bog peatland restoration are compromised by a fundamental lack of data on both the full economic cost of restoration and the likely ecosystem service benefits of individual restoration efforts (Moxey and Moran, 2014).

iii) Peatland Edge Woodland.

The final option for the future of afforested peatlands recognised by the Forestry Commission is so-called 'Peatland Edge Woodland' (Forestry Commission Scotland, 2015, 2016). This possibility is a compromise, largely driven by a desire by policy-makers to see an overall increase in woodland cover that supports a positive carbon balance and other environmental benefits. There is a recognition in government that the woodland cover of Scotland and the UK as a whole is very low by international standards and targets have been set to reach 25% woodland cover in Scotland by 2050 and 12% of the UK by 2060 (DEFRA, 2013; The Scottish Government, 2009). In Scotland, this is manifested in current large-scale planting of native species woodland, particularly Caledonian Pine forest (The Scottish Government, 2009). Woodland expansion and forest-to-bog peatland restoration have similar climate-related motivations, but the extensive removal of plantations from peatland makes targets for increased overall forest cover harder to achieve, particularly given that plantations are also being removed elsewhere for other reasons such as windfarm development. It is theoretically possible for all afforested peatlands to be restored and overall woodland cover to still be increased by more extensive planting on mineral soils. However, given the extent of afforested peatland in Scotland, this would be very expensive and is therefore not considered a likely scenario in the near-to-medium term. Additional expansion of forestry on upland mineral soils also poses risks to other high conservation value habitats. Peatland Edge Woodland is conceived as a 'middle way' option for peatlands, where standard commercial forestry practices may lead to a loss of carbon. Peatland Edge Woodland envisions peatlands with low density cover (500 stems ha^{-1}) of native species within their natural range. The aim is to create a habitat which achieves the best of both peatland and woodland. The concept is new and it remains to be determined whether Peatland Edge Woodland can be achieved in a way which both secures the peatland carbon stock and provides some of the biodiversity and ecosystem service benefits of woodland. The presence of naturally forested peatland in Scotland (albeit rare) suggests that trees and peat can coexist in the right circumstances, but whether this is possible in other geographic areas and on sites formerly used for commercial forestry is uncertain and the idea has been treated with scepticism by some scientists and conservation organisations (RSPB Scotland, 2014). Research is now needed to determine whether and how Peatland Edge Woodland can be achieved. Once developed, Peatland Edge Woodland sites are likely to require ongoing monitoring and active management to avoid the risk of 'runaway' expansion of tree cover and determine whether they are successfully delivering the desired outcomes. Maintaining a sufficiently wet surface to prevent peat oxidation while allowing tree survival is likely to be a key challenge.

Conclusions

Forestry on peat has been a contentious topic for more than 30 years and this continues to be the case. While conservationists might hope for total removal of peatland plantations, this is not realistic. Instead, as first rotation plantations reach harvesting age different sites are likely to be treated in different ways: some re-stocked, some restored to open bog and some planted with native species. The decisions which must be made now are about how this can be achieved and which of these options is best in which sites. Determining the right option for the future of peatland plantations requires difficult trade-offs to be made among biodiversity, the ecosystem services provided by different habitats and the value of commercial forestry. This is compounded by the difficulty of achieving government targets for both extensive peatland restoration and forest expansion (DEFRA, 2013). The rate and nature of future climate change introduces additional uncertainty into the future fate of peatland forestry and the feasibility of restoration as a climate mitigation measure (Boysen *et al*, 2017).

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