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Plantation forestry: Carbon and climate impacts

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ABSTRACT

Conifer forestry is expanding rapidly across western parts of the British Isles. This is promoted as good for climate, carbon and biodiversity. However, many spruce plantations are established by draining and disturbing peaty soils, which then release carbon and impair river ecosystems. This 'viewpoint paper' focuses on Scotland, and asks that investors and policy-makers recognise the damage being done by rapid afforestation and restocking. The author focusses on the drainage of peaty soils, and suggests that the incentives driving these changes are corrected in order to favour a better kind of forest.

1. Introduction: plantations on peaty soils

It is widely assumed that trees are good for the climate, but this is not necessarily the case, especially for some plantation forestry (Matthews et al., 2020; Brown, 2020). This viewpoint paper notes that most of the plantations in Scotland are emitting carbon, because current spruce plantation establishment and restocking techniques involve intensive draining of organic soils.

The problem is widespread in Southern Scotland, where investment forestry is booming. Conifers account for 57 % of new planting in the UK, but more than 75 % of Forestry and Land Scotland's 2020 planting (https://forestryandland.gov.scot/blog/there-s-more-to-conifers), and up to 88 % of new planting in southern Scotland (Southern Uplands Partnership, 2022). Most of this is one species, Sitka Spruce, a fast-growing American evergreen, planted densely so that little light reaches the forest floor. Sitka spruce is straight and easy to mill; cropped now in 30–35 year rotations (Confor, 2018), it is one of the fastest growing trees in the world, and prized because plantations sequester carbon fast from the atmosphere. However, most of Scotland's carbon is stored in peaty soils (NatureScot, 2015); wet peaty soils are where afforestation has prevailed (Brown, 2020) and when spruce is planted intensively on peaty soils (Map 1), especially where ditches are present, plantations can emit more carbon than they sequester (Matthews et al., 2020).

Forestry guidelines have recently been tightened to discourage new plantations on deep peat and to reduce cultivation intensity (Scottish Forestry, 2021), but clear-felled sites are still being replanted on deep peats, and drainage is still continuing on carbon-rich peaty soils (10–50 cm peat) (Scottish Forestry, 2022), all of which would be safer left intact, because carbon is stored more permanently in the soil than in biomass (Gregg et al., 2021). Map 1 illustrates how plantations imposed on peaty soils are particularly characteristic of the Galloway Forest Park, Kintyre and Argyll. These areas lie within the Atlantic Rainforest zone (Shrubsole, 2022; Averis, 2022), the UK's wet west, where rainfall can exceed 2000 mm per year, and the soils are organic (Map 1), where natural ecosystems favour wet woodlands and peatlands, and where engineering sites for spruce plantations involves draining land and flushing away excess water.

2. Plantations and greenhouse gas

Trees sequester carbon into biomass, and much of the industry research focusses on this beneficial impact. More recent investigation focusses on the soil, where three quarters of the carbon in UK forests is stored (Vanguelova et al., 2013; Vanguelova et al., 2018). Many of the soils available to spruce plantations in Scotland are wet, peaty and carbon-rich.

- Trees usually lock up carbon in soil (Laganiere et al., 2010; Sloan et al., 2019); but in peaty soils, the combination of decomposing litter and active tree roots causes peat to lose carbon (Vanguelova et al., 2018). For conifer forests on peat, the loss of deep soil carbon (Lilly et al., 2016) has been under-reported, because most studies only examine the topsoil (Mayer et al., 2020).
- Cultivation mobilises soil carbon. Mechanical cultivation is used to accelerate commercial forest establishment (Scottish Forestry, 2021). Cultivation techniques for plantations are often more intensive than those used for arable farming, and take place on

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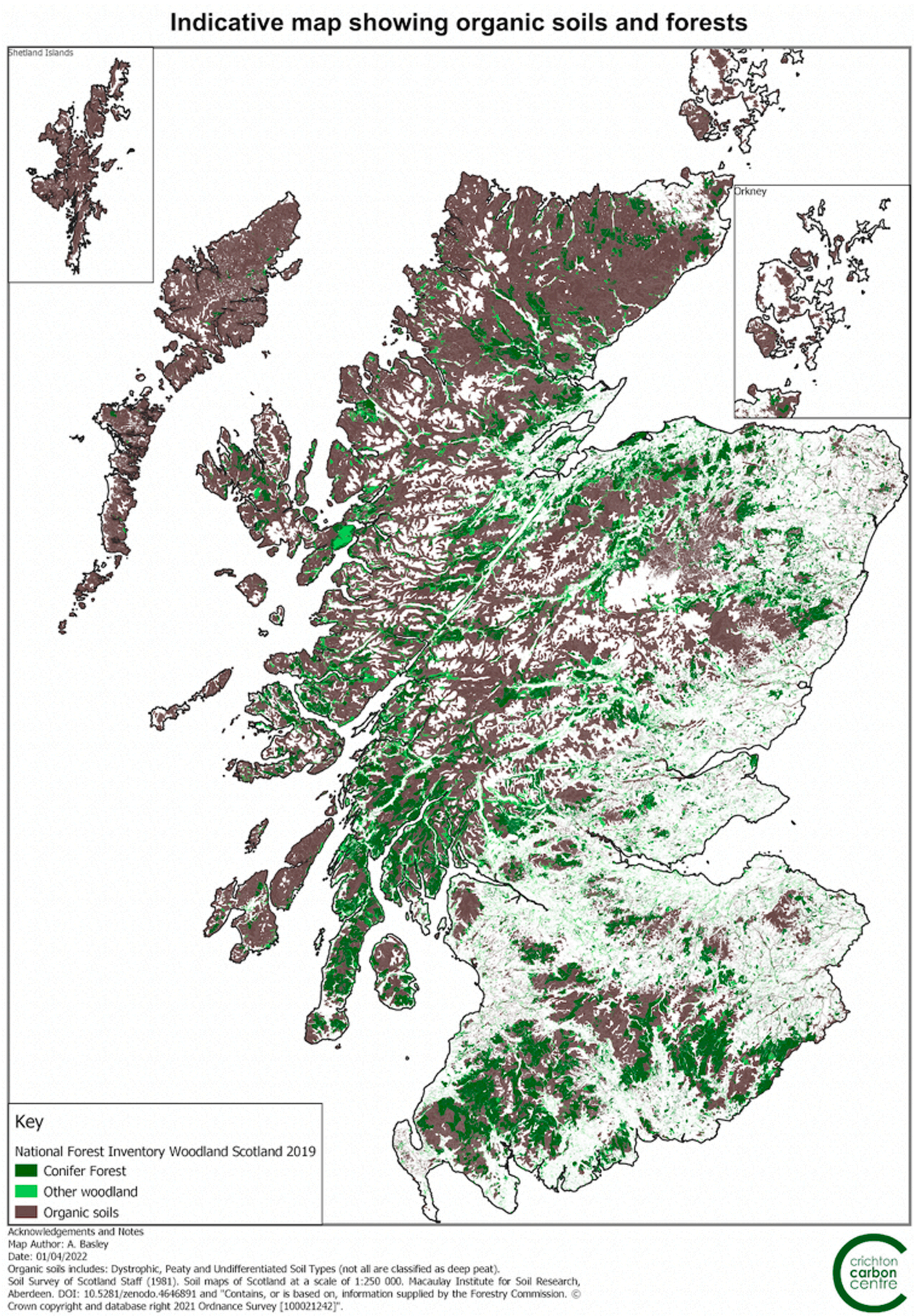

Map 1. Organic soils and forests in Scotland (Basley, 2022).

comparatively wild soils (including those which have never previously been ploughed). Techniques include ploughing, ripping, mounding and scarifying, and the use of fertilisers and weed-killers. At restocking, the cultivation effort is often even more intensive, because the tree-stumps, furrows and brash make the site very rough.

- Ditches have an unexpectedly powerful impact on carbon in peat; yet draining peaty soils is common practice in the UK (Evans et al., 2017a, 2017b). Drainage of peatland is thought to give rise to more emissions than any other land use change (Evans et al., 2016), and although important research has begun in areas with less than 1000 mm rainfall per year such as the Flow Country (Hermans et al., 2019), less is known about zones with much higher rainfall. Despite reminders that ditches should be accounted for (e.g. Peacock et al., 2021) many carbon flux studies do not properly describe or measure the impact of ditches on soil carbon.

2.1. Peat and peaty soils

Peat is formed of carbon, but is so slow growing that it is effectively non-renewable; an un-fossilised coal. In wet moorland soils, the carbon is stable if the peat is wet, but the carbon dissipates if the soil dries out. People have been trying to drain peat for centuries (Zehetmayr, 1954; Evans et al., 2016); unconcerned that carbon was being released (Vanguelova et al., 2018), and that carbon was flowing from the peat into the rivers. Fluvial organic carbon varies rapidly over time and space: fluvial carbon fluxes are often low during droughts, high (and difficult to measure) during post-drought floods and snow-melt; and the organic matter de-gases rapidly downstream (Cory et al., 2015; Evans et al., 2016), so often escapes un-measured.

2.2. Drainage ditches in peaty soils

Good drainage is effective in achieving rapid forest growth, and the timber industry engineers the land to suit spruce. Tracked excavators dig networks of ditches to remove water from wet sites (Anderson and Peace, 2017; Sloan et al., 2019). The modification of thousands of hectares of sensitive peaty ecosystem is intensive, yet this degree of upland and forest drainage is particular to the UK and Ireland (Evans et al., 2017a). When preparing a site for plantation, even sites that had previously been moor-gripped are re-drained; ditches are re-excavated and connected into an integrated drainage system. If the forest design and river buffering is exceptionally good (for example at the salmon river Halladale, Shah, Nisbet and Broadmeadow, 2021), conifer forestry need not damage the freshwater ecology. However, common practice in Scotland is much more intense, and in rainstorms, the furrows and ditches flush peaty carbon over the 'buffers' into streams. Ditches are anthropogenic features for which emissions need to be internationally accounted (Peacock et al., 2021), but the issue has not yet received sufficient research focus in the UK. Ditching and removal of 'excess water' seems to have become integral to commercial forestry culture (*pers. comm.* from several forestry contractors, 2022), in order to increase growth rates and enhance machine accessibility, yet new native woods, for example those planted by Trees for Life (*McConnell pers. comm.*), are not drained so intensively.

Although Scottish rivers are traditionally peaty, peatiness has increased in the last 30 years, especially downstream from conifer plantations (Blacklocke, 2016; Pickard et al., 2022; Jovani-Sancho et al., 2021). Rivers from drained forests on peaty soils have been estimated to release around 9.91 tonnes carbon dioxide equivalent per hectare per year (Evans et al., 2017a). Warm, dark, acidic, peaty water is detrimental to river water quality, river biodiversity, and reservoir water treatability (Freeman et al., 2001; Sloan et al., 2019), and has been linked to problems for water supply companies, creating public health issues (Ritson et al., 2014; Williamson et al., 2021). It had been thought that river acidification was mainly caused by atmospheric pollutants; yet now that the atmospheric pollutants are reduced, the peat-forested rivers remain too acidic for salmon to return. River headwater acidity is particularly acute in South West Scotland in the Galloway Forest Park, where unpublished but publicly available data shows that the rivers are the most acid in Europe, with acidity peaks intense enough to kill juvenile salmon (pH below 5.5, and sometimes as low as 3.7), and fish are now extinct from many areas of heavily drained peatland afforested with coniferous plantations.[1]

2.3. Plantation practices: cultivation, clearfelling and restocking on peaty soils

The mechanics of carbon loss from cultivating peaty soil are fairly well understood (Zerva et al., 2005; Swain et al., 2010; Simola et al., 2012; Chapman et al., 2013; Vanguelova et al., 2019; Lawrence et al., 2021), and it is now widely recognised that soil carbon loss increases with increasing intensity of the cultivation practice, drainage and soil disturbance (Scottish Forestry guidance, 2021). But some 800,000 ha of Scotland's existing forests are planted on peats (Vanguelova et al., 2016), so sites for replanting are often peatier than would today be permitted to be afforested. When these sites are re-drained and re-cultivated for the next rotation, the loss of carbon is even greater (Vanguelova et al., 2018), though much less well understood (Vanhala et al., 2013).

2.4. The net effect

The net effect of plantations on peaty soils is that many forests are emitting more greenhouse gases than they sequester; they are not carbon-beneficial (Matthews et al., 2020). Parts of Kielder Forest, just across the Scottish border, (Vanguelova et al., 2019) have lost large quantities of soil carbon from the peat, with approximately 30 % of original peat layer carbon stocks lost over one rotation (35 years). Soil carbon losses of around 3 tonnes carbon per hectare per year (11 tonnes CO_2 equivalent) have been reported (Zerva et al., 2005; Vanguelova et al., 2019; Jovani-Sancho et al., 2021); which is more than a fast-growing plantation can absorb. Worse still, the plantations are substituting safely stored carbon (peat) for a more reactive, unstable pool of carbon (biomass, timber products, waste). The most recent estimates for international reporting[2] suggest that on balance, forestry on peat is emitting between 1.15 and 5.46 tonnes of carbon dioxide equivalent per hectare per year.

Although the regulations are tighter now than they were when Kielder was planted; research shows that even where the peat is just 30 cm deep, the cultivation of peaty soils can lose more carbon that the trees can absorb in their 30-year life spans (Forest Research, 2022; and even on peats just 20 cm deep, it might take 15 years before net zero.

Furthermore, the effect of the forest ditches on carbon emissions from forestry may be greater than widely appreciated, despite the warnings of Evans et al. (2016). There seems to be a mismatch between what the forestry models predict, and what is being measured in the fluvial fluxes in the rainiest and peatiest regions. Recent research (Williamson et al. (2021) found that the UK's rivers contain more carbon than the global average, and much of this appears to be coming from forest plantations. The presence of conifer plantations can double the quantity of carbon lost from peaty soils compared with un-forested catchments (Williamson et al. (2021). Scotland's peaty plantations are

[1] For examples, see Forest Research's acid sensitive forestry map at https://forestry.maps.arcgis.com/apps/View/index.html?appid=0f618ca9de8640d0862ad113387b9704Also see research by Galloway Fisheries Trust at https://gallowayfisheriestrust.org/research-projects.php; and open-access water chemistry data requested from SEPA, © Scottish Environment Protection Agency 2019.

[2] 2021 update to the Emissions Inventory for UK Peatlands as reported by Gregg et al. (2021) for Natural England, later published in Brown et al. (2022)

exporting more carbon than we realised.

3. Why recent changes to forestry guidance are insufficient

As new evidence emerges, conventional wisdom is being questioned. Twenty years ago, the convention was that Sitka spruce plantations on peaty soils grew so fast that they were net carbon-positive. But in 2017, after reports began to show that forests on peaty soils were emitting more carbon than expected, the UK government realised that emissions from peat under conifer plantations make a major contribution to UK peat GHG emissions, and would need to be reported to the IPCC as part of the UK's greenhouse gas emissions inventory (Evans et al., 2017a). It is possible that this divergence arose because of the different methods used to calculate carbon fluxes (forestry reporting relies on temporal models for the cycle of planting, growth and harvest, whereas Land Use and Land Use Change reporting relies on measured fluxes from different land uses; CEH, 2019), but the evidence showed that continued intensive afforestation and replanting of forests on peat was not contributing to UK efforts towards net-zero carbon emissions (Brown, 2020).

By 2018, it became apparent that guidelines on forest cultivation, especially ploughing, needed to change in order to reflect the climate emergency. Yet when forestry regulators began drafting guidelines, there was resistance, claiming that the research was flawed or uncertain. The draft guidance advised against the easiest methods of planting forests on peaty soils, but the regulators were pressurised to withhold publication of that guidance for more than 3 years, (Lawrence et al., 2021). In 2021, after legal challenges emerged about the supposed carbon benefits of new plantations on peaty soils, the Forestry Commission in England published the new guidance, and later that year Scottish Forestry followed suit (Scottish Forestry, 2021). Soon after, Scotland's Cabinet Secretary for the Environment warned[3] that Scotland's land use should now be recognised as a net GHG source, and that much of this was a result of drained peatlands, including the use of peatlands for agriculture and forestry.[4] The delayed publication of the guidance resulted in several years of public and private sector finance being funnelled into schemes presented as climate-friendly but which were probably carbon-emitting.

Afforestation of the Flow Country fifty years ago was soon recognised as an environmental mistake (Warren, 2000). There are parallels today, as investment funds fuel the boom in new forestry in Southern Scotland, trusting that conifers and carbon credits are a green investment. National and international initiatives such as the Taskforce on scaling Voluntary Carbon Markets are working to improve the credibility of voluntary carbon credits; but market forces have created powerful expectations, and have not warned that carbon credits might become carbon liabilities.

The Woodland Carbon Code[5] was designed to predict the effect of forestry on carbon. The Code, internationally accredited and regularly updated, was originally focused on biomass, but includes sub-models on soil, linking back to the underlying CARBINE model (Forest Research, undated). It is difficult to work out the extent to which the current Code takes drainage ditches in peaty soils into account, (and unlikely that any models can predict just how effective forest contractors are when encouraged with incentives for forest cover, rather than peatland protection), but the mismatch between the models' predictions and the measured carbon emissions from peaty forests suggest that the estimates used by the models underestimate carbon emissions from peaty ditches, both at afforestation and restocking. This finding concurs with the IUCN's position paper on forestry on peat (IUCN, 2020).

[3] https://archive2021.parliament.scot/S5_Environment/General%20Documents/ECCLR_2021.02.05_CCPu_IN_CS_UK_GHG.pdf

[4] https://www.gov.scot/publications/future-revisions-to-scottish-greenhouse-gas-statistics-associated-with-ipcc-wetlands-supplement/

[5] https://woodlandcarboncode.org.uk/

It is therefore disappointing that the new guidelines (Scottish Forestry, 2021), good though they are, restrict themselves to cultivation techniques, when wider research, as cited above, shows that net carbon losses are caused by the drains, ditches and restocking.

Five suggestions would help remedy the situation:

1. The assumptions and parameters underlying the current forestry carbon models should be verified using empirical evidence, and the models re-calibrated if necessary;
2. In the meantime, to safeguard soil carbon, the current exclusion of planting on peats more than 50 cm deep should be extended to shallower peaty soils (those with 10 cm or more of peat); and excavation of new ditches in peaty soils should be proscribed.
3. After harvesting timber from peaty plantations, soil and carbon conservation should be prioritised, instead of restocking for further spruce production.
4. Monitoring (and enforcement if necessary) of the regulations and guidelines on afforestation of peaty soils should be increased.
5. Investors should audit their forestry investments, to ensure their portfolio is genuinely green, that no peatland is damaged, and that any run-off, including ditch-water, is unpolluted and contains minimal organic matter.

Government regulators will need to be stronger, and our policy makers more careful about the type of land use change they are encouraging, if they are to meet net zero targets and tackle the climate emergency.

4. Summary

The forest industry promotes conifer forests as carbon positive; yet many plantations are emitting carbon. This paper has presented a series of arguments which show, incrementally, that:

1) Ditches and drains are the overriding reason for peatland losing its carbon (e.g. Evans et al., 2016).
2) Most of Scotland's forestry has been (and is still being) planted on organic, peaty soils.
3) The UK forest industry uses intensive ground preparation on wet, peaty soil in order to grow spruce, excavating networks of ditches and drains to flush away water from plantations.
4) Ditches, streams and rivers in afforested catchments are heavily loaded with carbon; the forests are losing carbon through the drains. (CEH, 2019: Figure 4; Williamson et al., 2021).
5) The problem is acute in south west Scotland, where afforested headwaters contain high levels of organic carbon, and lethal spikes of acidity. (e.g. data from SEPA and Galloway Fisheries Trust).

In parts of the UK, we have been planting the wrong type of forests, in the wrong place, and using the wrong techniques. If we want woodlands to lock up carbon for centuries, we need to move away from draining and disturbing peaty soils to suit plantations, and instead develop more sustainable models of forestry and soil conservation.

Declaration of Competing Interest

None.

Data availability

No data was used for the research described in the article.

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