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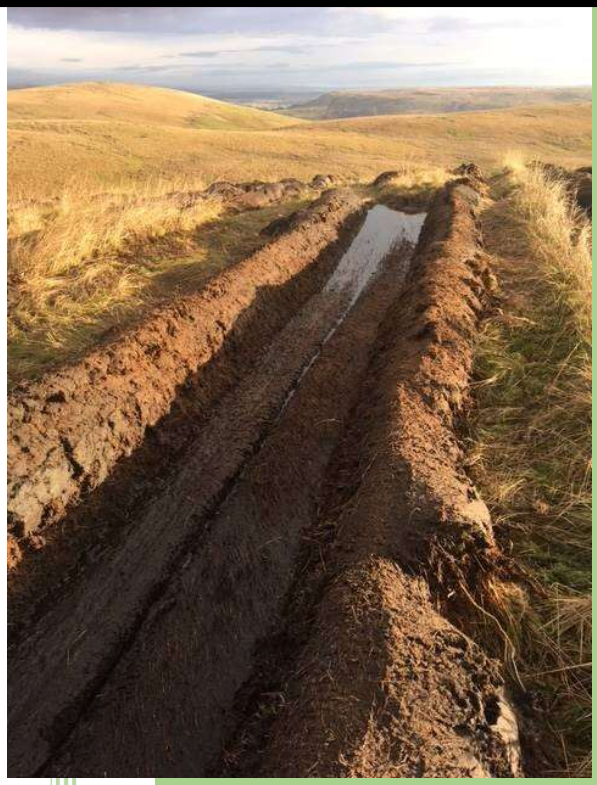
Forestry and Soil Carbon in Scotland: science, practice and policy



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1 Summary

The evidence shows that forestry can and should better contribute to the government's NetZero target by 2045. Changes to forest policy, guidance and practice would reduce emissions of greenhouse gases from forest practice on peaty soils.

Tree planting and forestry are seen as positive ways of offsetting Scotland's greenhouse gas emissions because trees sequester carbon. The Scottish government has encouraged an expansion of forest in the Scottish uplands and large areas have been planted into peaty soils where much of Scotland's carbon is stored.

When peaty soils are disturbed they act as sources of greenhouse gas (GHG); the degree to which peaty soils act as greenhouse gas sources is dependent on the intensity and scale of the disturbance. Evidence suggests that forest operations – draining, cultivation, clearfelling, and restocking – contribute to GHG emissions. At the time this study was commissioned, there was conflicting evidence over whether trees might grow fast enough to offset this loss and during the study period it has become clear that forest practice needs to keep as much carbon as possible in the soil.

Soils are not legally protected and are poorly regulated, while technical guidance for practitioners is patchy. The Scottish regulatory body Scottish Forestry has, despite industrial forestry opposition, released progressive, precautionary cultivation guidance to address some of the environmental and climate change concerns about ploughing on shallow peat. Forest Research has produced guidance for other aspects of forest practice on peaty soils such as restocking on deep peats; however, this guidance now needs updating.

Interviews with forest stakeholders illustrated the drive, professionalism and culture which helps make the forest sector so innovative. If given clear guidance on climate targets, forestry should be capable of growing and harvesting trees in a more sustainable and soil carbon friendly manner than is currently the case.

We recommend that Scottish Forestry should highlight the importance of forest soils in the next iteration of Scotland's Forest Strategy, and the forest sector should give clear messaging about the importance of keeping carbon in the soil.

We recommend that the industrial sector should place greater emphasis on foresters being soil carbon managers. Forest practice should adopt the precautionary principle and minimise peaty soil disturbance. Afforesting mineral soils, rather than peaty soils, should become a higher priority. The excavation of drains and ditches in peaty soils for cultivation, clearfelling and restocking should be phased out. Natural regeneration should be encouraged both for forest establishment and for restocking. A stronger focus on 'good forestry' in external portrayals of the sector would help the public understand professional values.

We suggest that regulators need more resource and increased budget for guidance, monitoring and regulation, and to speed up good applications. If government and the regulator are to provide a lead in working towards NetZero, they need to adopt a clearer and more proactive approach to resourcing science and adopting the precautionary principle. Terminology within the guidance on soils should be changed such that "shoulds" become "musts".

We recommend that science should fill the gaps on:

- using natural regeneration for establishing and restocking forests
- using less intensive silvicultural systems such as CCF;
- clearfell harvesting and restocking on peaty soils;
- establishing carbon balances for industrial forests over multiple rotations;
- modelling native woodland establishment without drainage and mechanical cultivation.

2 Introduction and background

2.1 Aims and approach of this study

This study was commissioned by the Pebble Trust (Pebble Trust | Home (thepebbletrust.org)) which supports projects contributing to its vision of 'a more sustainable, equal and low-carbon society'. The study is intended to inform policy makers and practitioners about the impacts of forest practice on soil carbon and how such impacts may be mitigated. The objectives include reviewing relevant science, particularly in relation to peaty organic soils; a study of current practices, knowledge and perspectives of forestry stakeholders; and an assessment of the legislative and policy tools available to shape practice.

The review of scientific and technical information is based on a literature search for papers that reference soil carbon and forest practice, primarily in the UK, and including research on different soil types but focusing on organic soils, and with reference to broadleaved and conifer woodland. Forest Research staff provided guidance on key scientific papers.

The views of forestry stakeholders (sections 3, 5, and 6.5) are based on 16 interviews with commercial forest managers, independent agents, public sector forest managers, contractors, regulators, and forestry membership bodies, about what they do and why they do it. The themes identified in these interviews are illustrated with typical quotations.

Each component of the study is reported in detail in separate papers, available online at Forest Policy Group – for sustainable forestry in Scotland. This summary report combines all three components in order to consider their implications and make recommendations.

2.2 Background: climate change, carbon and climate policy in Scotland

Headlines related to recent extreme weather are becoming more frequent: Widespread wildfires fires in developed and developing countries, deadly flooding in Germany and Belgium in July 2021 washed away people, buildings and cars, and hundreds died in flooding in China. The U.S. Pacific Northwest and Western Canada, with cool temperate climates, experienced temperatures above 100°F for several days. And the Arctic lost an area of sea ice equivalent to the size of Florida between June and mid-July 2021.

These changes are happening with average warming of 1.1 degrees C (1.98 degrees F) over pre-industrial levels. The Intergovernmental Panel on Climate Change (IPCC), the world's most authoritative body on climate science, states that this is just a taste of what's to come. The IPCC Working Group I (one) sixth assessment report shows that the world will probably reach or exceed 1.5 degrees C (2.7 degrees F) of warming within the next two decades.

The conclusion of an independent assessment (Climate Change Committee June 2021) led by the Climate Change Committee (CCC) which considered a catalogue of risks and opportunities affecting concluded that action to improve the UK's resilience to climate change is failing to keep pace with the impacts of a warming planet and increasing climate risks facing the UK.

In April 2019 the Scottish Government declared a global climate emergency with a time horizon of 2045 for achieving a target of 'Net Zero' greenhouse gas emissions. A road map for achieving Net Zero was published in December 2020 and part of this map, referred to in the climate change plan (2018-2032) relates to Land, Land Use Change and Forestry (LULUCF) emphasising woodland creation and peatland restoration.

2.3 Background: forest expansion in Scotland

Scotland has expanded its forest area from 5% to 20% in the last century. Much of this afforestation has taken place on marginal ground on peaty soils in the uplands, by draining and ploughing wet moorland and grassland to create suitable planting sites for trees (Map 1).

The dominant forestry system in Scotland is even aged plantation clearfell, it is industrial[1] in nature and relies heavily on one conifer species, Sitka spruce. It is to a large extent driven by maximising financial returns, involves intensive often large-scale interventions and has caused concern to local communities, NGOs and policy makers, most recently vis a vis its impact on soil carbon in peaty soils.

Many new forests established in the 1970s and 80s were in sensitive landscapes such as the Flow Country of Caithness, where ploughing and draining of peatland habitats provoked such a public outcry that the UK Government removed the tax incentives responsible for driving this phase of investment forestry.

Peat is made of organic carbon. Deep peats are defined in Scotland as those >50cm deep (such as in blanket and basin bogs). Shallow peats (in this report "peaty soils") are 10-50cm deep and include organo-mineral soils such as peaty gleys and podzols.

A new phase of forest expansion is underway in Scotland in part driven by continued government exemptions from inheritance and capital gains tax, also because of generous planting grants for industrial conifer afforestation introduced by the Scottish Government in 2016. The Woodland Grant Scheme has its roots in the Woodland Expansion Advisory Group (WEAG) report (June 2012) which laid out the policy context for increasing Scotland's woodland area, referencing the Scottish Governments Low Carbon Scotland [2]strategy with actions to achieve national emissions reductions, one of which was planting 10,000 hectares of new woodland per annum from 2010-2022. The WEAG report presented a new direction for woodland creation predicated on new woodland being more diverse, more inclusive, more positive, more resilient, but above all, more productive, with a higher percentage of new woodlands designed to produce biomass and timber. Linking climate change mitigation and timber productivity as policy drivers, the Scottish Government has provided attractive public planting grant finance, and further reduced 'red tape' for woodland creation following the Mackinnon Report (Mackinnon 2016).

2.4 Background: Soil cultivation in forestry practice in Scotland

Methods of cultivating land for trees ('ground preparation') evolve with technology, ploughing became commonplace in Scotland after the Second World War when the double mouldboard plough was developed, and caterpillar tracks allowed access to deeper peats and peat bogs. Mechanical cultivation to improve tree productivity on poorly drained sites containing peat or peaty soils is common practice. It is intended to increase initial survival rates and allow faster tree establishment, a

Between the 1950s and 1980s, approximately 9% of the UK's deep peats were drained for forestry (Hargreaves *et al*, 2003) and a recent evidence review reported that 21% of shallow peats and 17% of deep peats in Scotland are forested (Vanguelova *et al*. 2018).

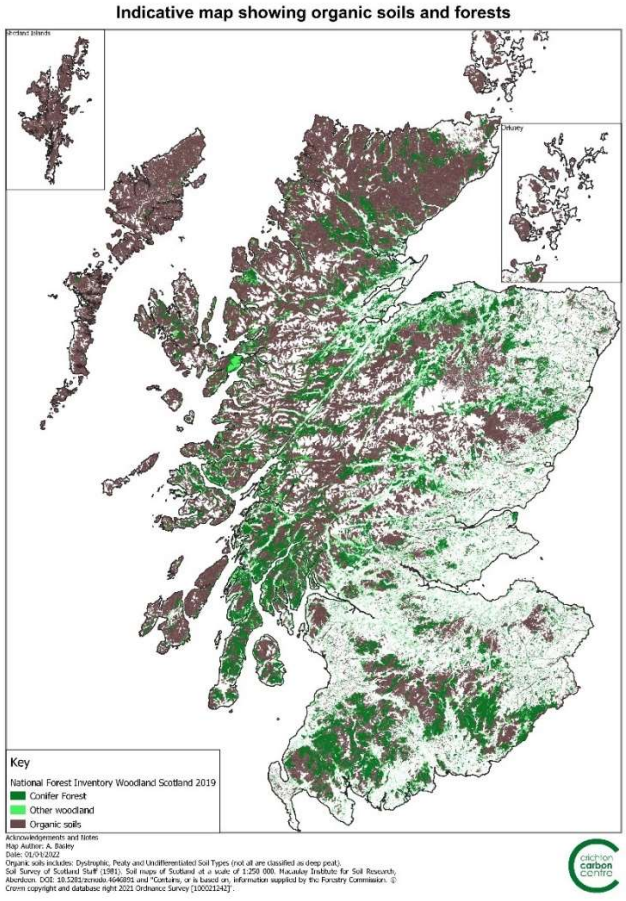
[1] The term Industrial forestry is used to refer to even aged clearfell plantation forestry, mostly composed of a single species, Sitka spruce. The terms commercial and productive can be applied to broadleaves and diverse conifer species.

[2] http://www.scotland.gov.uk/Topics/Environment/climatechange/scotlands-action/lowcarbon/rpp

raised planting position provides a microsite free from competing vegetation with improved drainage, temperature, and enhanced nutrient availability.

In recent decades forestry has improved machinery and technology for cultivation pre-planting. Techniques such as continuous mounding, patch scarification, inverted mounding, hinge mounding, trench mounding and line scarification are, in the main, less aggressive and disturb less soil carbon than ploughing. However, some private forestry management companies, in partnership with their investment partners, appear wedded to ploughing peaty soils.

Cultivation that disturbs the soil increases aeration and mineralisation which in turn generates carbon emissions from a breakdown in organic matter. Mechanised techniques differ in their intensity and impact on soils. Deep and shallow ploughing are the most intense and have the greatest impact on soils; disc scarification and trench mounding are moderately intense, inverted mounding and patch scarification are less intense, while screefing and flat planting have minimal impacts (West, 2017). Natural regeneration has no immediate impact on soils however drainage has a profound effect due to the drying of peat.



Map 1. Organic soils and forest cover. Map used with permission, Crichton Carbon Centre.

Data sources: Soil Survey of Scotland (1981, Macaulay Institute for Soil Research) and Forestry Commission (2021)

Forestry Commission Scotland (FCS) effectively banned tree planting on 'deep peat' (peat more than 50cm depth) and Scottish Forestry, the successor to FCS, has produced progressive and precautionary cultivation guidance based on the most up to date science from Forest Research. Early in 2021, Scotland's Cabinet Secretary for the Environment warned that Scotland's land use should now be recognised as a net GHG source, much of this is a result of drained peatlands, including the use of peatlands for agriculture and forestry.[3]

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

3 What are practitioners doing and why?

In this section we explore current forestry practice in relation to soils, through the eyes of forest managers, agents and regulators.

3.1 Practice

3.1.1 Change since 1980s

Opinion from across all stakeholder groups highlighted that forestry practice had changed and improved since the 1980s. Many in the private sector felt that they were still judged on the practices of the 1980s and that government agencies, NGOs and the public need educating to understand the changes that had been made.

> *As an industry we are still tarred with the brush of the 1980s. The agencies and NGOs don't understand modern forestry. That's disappointing.* [independent agent]

> *I thought a few years ago we'd gone forward, we were getting fewer commercial schemes, but obviously the larger scale stuff has come back on the agenda.* [regulator]

Regulators noted however that recent increase in support for commercial conifer afforestation had led to a return to inappropriate ground preparation.

3.1.2 Ground preparation for woodland creation

A key focus of discussion was ploughing. There was no consensus within any stakeholder group, about the merits or otherwise of ploughing. Arguments both for and against ploughing are based on experience, direct observation, belief and claims of expertise. Older foresters tend to have stronger views. In the private sector those in favour of (at least some) ploughing use arguments of efficiency and cost-effectiveness based on drainage, weed control and speed of seedling establishment.

Those who felt that there was no need for ploughing at all, and that a blanket ban would be desirable, were represented in all stakeholder groups except private forest management (FM) companies. In addition to carbon impact, reasons not to plough include safety, need for supervision, and landscape impact. There was a view that the shift away from woodland creation on deep peat meant that ploughing was no longer needed.

> *The most important thing for us is to get the trees established as quickly as possible – on peaty soils, wetter soils, we'd prefer to plough.* [commercial FM company]
>
> *In west Argyll ploughing is fantastic. It worked in the 60s 70s 80s, and it works again. Scottish Forestry's attitudes have changed but it works.* [different commercial FM company]
>
> *I see ground prep that looks to me to be more aggressive than it needs to be ... We see these long cultivation scars running straight up and down the hillside.* [Members organisation]

> *One of the big issues is the accuracy of mapping of deep peat soils.* [independent agent]
>
> *A lot of sites are incredibly variable in terms of soil. I'm constantly amazed by the amount of finesse required of a FM and machine operator to match the ground prep to the soil map.* [membership organisation]
>
> *Difficult sites are mosaics of deep peat and shallow peat* [commercial FM company]

The definition of deep peat as 50 cm or more, and the ban on cultivating such soils, is widely accepted; stakeholders across the spectrum indicated they had no problem with that. Many commented however that the scale at which the 50 cm rule is applied in soil mapping and site survey, creates problems for them. Many reported difficulties with accuracy of soil mapping, increasing expectations of finer scale soil survey, and rising costs associated with that.

3.1.3 Ground preparation for restock

We have walked over lots of restock sites in our lives, they are terrible places. The trench mounding is so aggressive. [independent agent]

Restock ground prep is a huge issue. The aggressiveness very much depends on the experience of the forester and the contractor. I have seen some horrendous sites. [different independent agent]

Restock is a bit of a blind spot - people are getting incredibly interested on how you prepare the ground at afforestation but ignore what happens at restock. So they're doing pretty invasive ground prep at restock. Most commercial sites are all mounded. That's quite a lot of digging about. Some of those sites are quite peaty. [private sector FM]

Across the spectrum of stakeholders there was a strong view that ground prep for restock is a greater concern than for woodland creation, in terms of carbon loss and other environmental damage. This is because restock often takes place on deep peat where new planting would not now be permitted; ground preparation uses more aggressive methods (e.g., trench mounding); and restock is subject to less regulatory oversight than is new planting.

For several respondents this was where they found the opportunity to bring about change, exercising professional judgement rather than responding to regulation.

Restock is an opportunity to put right the wrongs of the 60s, 70s, etc. It's the only chance, a short window to put something better back on that landscape. [regulator]

When restocking we are looking at the sites and taking out areas that might have been planted inappropriately in the first place e.g. wetland. [independent agent]

I looked at colleagues who were doing trench mounding, my gut instinct told me that's not right, effectively you are putting in deep trenches … so I decided in my district we're not going to trench mound. [commercial FM company: senior manager]

Brash recovery has made a massive difference to planting the site. You don't need to do trench mounding because it leaves a clear site [contractor]

The public sector has more of a focus on restock than on woodland creation. Several pointed out that changes in practice (e.g., a move away from using fertilisers) meant that sites that had formerly yielded well would no longer do so and should not be restocked, while the use of improved Sitka might justify restocking. Professional judgement and site knowledge are applied more than guidelines such as FR or FCS publications[i] on what to do on peat. Some felt increasingly the logic of allowing such sites to revert to (restored) peatland.

You're allowed to do restock on deep peat if you believe you'll get yield class 12. So if you are putting in improved Sitka and drain it properly, could you get it away? On some sites you can, on others you can't. It's not just as simple as "deep peat". [commercial FM company]

*I think I'm beginning to be persuaded that there are carbon capture benefits to peat restoration. [*public sector FM*]*

I've been looking at sites in the north that should never have been planted. You can't restock those sites without deep draining. You need to take the trees off and leave them. At the moment there isn't the incenti for a landowner to do that. Maybe they should get an incentive. [independent agent]

3.1.4 Pragmatism, idealism, and compromise

Although some talked as though they were locked into a battle of irreconcilable values, most considered that the main task was to get approval and avoid delays.

Views on how this pragmatism translates into good practice or cutting corners, varied. Some foresters felt this focus on pragmatism brought standards down and meant that they had no time for taking the initiative to do better forestry, in both private and public sector. There was also a widespread view that carbon concerns have to be balanced with other concerns, such as use of herbicides and pesticides.

*It doesn't matter if anyone cares, the point is there is clear guidance - if the water is running dirty you need to do something about it. This is from a legal not a moral point of view. People do the minimum they can get away with. Every time you do more someone is paying. [*commercial FM company*]*

*In an ideal world I would like to be focusing on how we can improve things for the future. But we are just trying to survive and cope. We have targets and that's the main focus. [*public sector FM*]*

*Over on the west where the terrain is brutal for growing trees you lose that [concern about carbon] because you are panicking to get the trees away. When you get inspected you are good to go. [*commercial FM company]

3.2 Influences on practice

For most participants, 'professional culture' is the most significant influence on practice, followed by the wishes of clients and (usually, but not always, related) costs.

3.2.1 Professional culture

Professional culture, or the accepted and shared norms for doing forestry, is often cited particularly by private sector foresters. Interviews however revealed some shared and some divergent values underlying forestry practice.

The ploughing enthusiasts were generally in the private sector.

I like trees. I don't want to plant loads and loads of Sitka, I would like to plant other things. [commercial FM forester]

We are fixated on releasing carbon … I get that but I'm a tree farmer, I grow trees for a living, if the medium is good enough to grow a tree then let's grow a tree. [different commercial FM forester]

I'm in forestry because I like the environment. I'm practical enough to know I'm producing a product. But I want that to be long term sustainable. [independent agent]

Several thought that difference in professional values was related to age. Across all the sectors, some made amusing remarks about 'dinosaurs' who were reluctant to change.

He comes with that [commercial FM company] culture. He's a dyed in the wool plougher! But there are people in the public sector who favour ploughing too. [regulator]

Private-public sector interactions: where one is chasing profit and the other is conserving value. [commercial FM company]

It's the old private sector / FC stand-off. Amongst some of the bigger companies it's ridiculous. Some say, "Let's kick the FC because it's a government organisation." [independent agent]

Forestry is in the dark ages compared with agriculture. You know, these old school foresters are still hovering around what was developed in the 50s [commercial FM company]

Old attitudes of 'What we want we get' still exist. Now we're having a bit of dummy-out-of-the-pram because the government has dared to challenge their domain. It's lots of oldish men puffing their chests out talking about the old days when they could plant trees right up to the river. We have got to move forward to proper SFM. [regulator]. *The older lot, we ploughed everything, way back, and we still tend to quite like ploughing, whereas the younger staff seem to not like it.* [commercial FM company]

However, some pointed out that younger foresters may also have less confidence and experience to negotiate a more nuanced decision with woodland officers.

I have a huge degree of sympathy for the younger foresters coming through. Someone towards the end of their career has the nerve to turn round to the woodland officer and say, 'My experience says this is correct.' It's much more difficult for younger foresters to take that line. [independent agent]

The guidance is not executed by Scottish Forestry very well, because they don't employ foresters. For example, we've got a new case officer starting who doesn't have the experience, the time served planting trees. All they have is the guidance … so they stick to that. [commercial FM company]

Many in turn felt that Scottish Forestry is under-resourced and woodland officers lack experience to make decisions.

Lack of resources was also reflected in public sector forest management.

When I joined it was more of a vocation. We're [now] feeling quite exploited. The little bits of overtime to see that site. The constant change, constant adaptation to the latest trend. And that's before you start doing your actual job as a forester. [public sector FM forester]

You know I think the forestry groups have to be careful not to be against each other and get nothing done. Any negative press they will jump on it. [contractor]

Some of the people arguing against ploughing are in the forestry camp but sniping against it. It's not long before they start sniping against big investors. It sounds like they have a socialist agenda. [commercial FM company]

Some in the private sector thought that foresters should be sticking together and were unhappy to see divergence in views which might open them up to criticism.

3.2.2 Clients

As well as professional values, the values of the client are a main factor influencing the private sector. On the whole, stakeholders reported clients' main motivation to be return on investment. However some reported the emergence of a new more environmentally-aware type of client.

> *My big clients are commercially minded so I'll do what's cost effective.* [contractor]
>
> *The owners' woodlands have to pay. But clients also understand that it has to comply with sustainability, because they are motivated by transfer between generations.* [independent agent]

> *I think [FM company] get a really bad press because they are out to maximise the pound but that's kind of their job depending what kind of client they work for. [contractor]*
>
> *Client impact is what shapes what I do. They pay my bill and I have to advise them on what I believe meets their management criteria best. I have yet to do a long-term forest plan where one of the client's stipulations is carbon. [*commercial FM company*]*
>
> *Carbon would be one topic at the moment that I would click on and download. Investors are keen on it so being across what's going on is important.* [independent agent]

Some in the private sector (particularly independent agents) felt that despite clients' focus on financial returns, the agent could still influence good ground preparation, and pointed to the FM companies driving the preference for ploughing.

> *It's the management companies driving it more than the investment companies. They [clients] have a lot of money; they are going to do forestry whether they can plough or not. Anyone who tells you otherwise is talking nonsense. It's the FM companies leading it, they are saying "We want to be able to plough, the bloody FC is stopping us!"* [independent agent]

3.2.3 Contractors

Interviews highlighted the role of contractors in influencing practice. Regulators, commercial FM companies and public sector forest managers all had examples where the contractor had influenced outcomes for better or worse.

> *We were using diggers to make a mound, I thought there must be an easier way. A digger is £5-600 / ha and on a good day will do a hectare, using 130 litres of diesel. The Enviro-mounder will do 6 ha and uses 100 litres of diesel for a whole week.* [contractor]
>
> *[The new machine is] spreading all over Scotland …. The foresters were over the moon. [*different contractor]

> *We hardly ever plough. Continuous mounding is a lot cheaper now than it used to be.* [contractor]
>
> *Five years ago we used more sophisticated imported machines, which cost more. But now we've got much simpler continuous mounders - for most sites they do a good job and are cheaper.* [regulator]

The role of contractors in innovating to design machines with lower impact was widely recognised. Reduced cost and increased availability mean that many have equipped themselves with mounders because of innovations that have reduced the cost. A wide range of stakeholders commented on this as underpinning a move to continuous mounding.

3.2.4 Public and other stakeholders' perceptions

For regulators, public reactions to certain types of ground cultivation are an important factor.

> *Ploughing is about the public perception – I know from experience, you can do all the consultation you like, some schemes go through smoothly, then the plough arrives and starts to go up and down the hill, and that's when the locals take notice [and start to complain]* [regulator]

Many in the private sector in contrast felt that the public has a poor understanding of forestry, and that the sector is misunderstood.

> *Farmers don't consult their local communities when they plough their fields or whatever! We consult every time we write or change a management plan. It's blinking hard work I tell you. We are going through the birthing pains of having to educate the communities about what we do. … Environmentalists are still opposed to productive conifer. We get these negative comments all the time. I don't think these people get it.* [commercial FM company]

3.3 Summary: What we learnt about forestry in practice

- Ploughing is popular in the commercial forestry sector, and amongst older foresters, but not universally so.
- Ploughing is an issue for new woodland establishment, not for restock. However many practitioners feel that ground preparation for restock is as much of a concern as woodland establishment, and that practices around restock are overlooked and under-regulated.
- Some see harvesting and restock as an important opportunity to change from 'old-fashioned' forestry to better methods, or even to move to peatland restoration.
- Contractors have an important and possibly overlooked role in innovating to make better practice possible. The spread of lower-impact mounding can be traced back to one or two individuals who have designed suitable machinery for Scottish conditions.
- Professional culture plays a role in setting out acceptable practice, but it is clear that there is a wide range of interpretations of what is acceptable. Public opinion plays much less of a role in influencing practice.
- The commercial sector emphasised the influence of clients on practice. Most highlighted the role of finance, and the drive to maximise return on investment. A few foresters indicated that clients are more sophisticated and that more carbon-friendly forest establishment is welcomed with minimal impact on financial returns over the full rotation.

4 What does science tell us about the impacts of different forestry practices on soil carbon?

4.1 Introduction

This section draws on a mix of primary and secondary research including evidence assessments of forestry practice on peats, most of it from the UK and Ireland.

Forest carbon sequestration through growing trees is well understood, extensively modelled and relatively non contentious. But carbon cycling in soils, especially peaty soils, is complex, and the science of the effects of forestry practices on carbon stocks and flows is still developing (Sloan *et al.*, 2018; Vanguelova *et al.*, 2018, 2019), with scientific analyses sometimes being inconclusive or contested (Reynolds, 2007; Mayer *et al.*, 2020). In 2020, two soil carbon scientists from Forest Research wrote: "There *are presently insufficient measurements from a range of UK climate, land-use and soil type conditions to quantify with confidence soil carbon changes during afforestation."* (Perks & Vanguelova 2020). Why is this?

Barriers to obtaining conclusive results on the magnitude and flows of soil carbon include heterogeneity of soils over small scales, variable distribution of carbon within soils, and the relatively slow changes of carbon stock (Vanguelova *et al.*, 2016). The use of different scientific research techniques, which measure different soil carbon variables, adds to the complexity of interpreting soil carbon changes, and sometimes divides scientific opinion (Sloan *et al.*, 2018).

An example of the limitations of our understanding of how soils work is seen in the scientific debate surrounding the longevity and recalcitrance of humus. Although peat is widely recognised as being stable over thousands of years, the classic view of humus was that it is stable, locking in large carbon-rich molecules for perhaps hundreds of years. However, this paradigm has been challenged through technological advances in electron micrograph imaging demonstrating that large carbon molecules in humus are susceptible to break down by microbes (Popkin, 2021).

4.2 Forestry practice

Some three quarters of the carbon in UK forests is stored in the soil (Vanguelova *et al.,* 2013). What happens to soil carbon because of forestry practices depends on three factors (Vanguelova *et al.*, 2018):

- The soil type. In mineral soils such as in ex-arable and improved grassland, soil carbon stock tends to be stable. In peat soils, often unimproved pasture and moor, the carbon is stable if the peat is wet, but the carbon can be labile and easily mobilised if the soil dries out - there is often a loss of carbon from peat underlying forests (Lilly *et al.*, 2016).
- The tree species, the rate at which trees grow and the development of the soil litter. Most soil carbon studies have looked at changes to soil carbon in the topsoil (0-30cm depth) (Mayer *et al.*, 2020). Conifer litter creates an organic surface layer and development of the litter and forest floor layer is the main contributor to soil carbon in woodlands especially in conifer woodlands (Laganiere *et al.*, 2010).
- The level of disturbance to soils caused by forest practice. We look at three practices which have significant impacts on forest soil carbon in Scotland:

a. Intensive cultivation for woodland creation – mostly, but not exclusively, used to establish industrial forests including draining, ploughing, mounding and other mechanical establishment techniques. Mounding and sub soiling are used to create native woodlands.

b. Clearfelling of industrial forests - roads are constructed, drains cleared and deepened, processing machines fell and process trees, and forwarders extract processed timber to roadside.

c. On completion of clearfelling, sites are readied for restocking by draining, mounding, and/or scarifying.

4.3 Soil carbon and cultivation

Afforestation of mineral soils such as ex-arable land does not result in significant release of GHGs and can result in significant increases in soil carbon over long time periods (Ashwood, F., *et al.* 2019, Poulton, 1996, Benham *et al.*, 2012). This is partly because relative to peaty soils mineral soils contain low levels of carbon.

Ploughed peat, Langholm, December 2020. Photo: Christopher Nicholson

Peaty soils are different. Most research concludes that cultivation of peaty soils results in losses of soil carbon (Zerva *et al.*, 2005; Swain *et al.*, 2010; Simola *et al.*, 2012; Chapman *et al.*, 2013; Vanguelova *et al.*, 2019), quantification is difficult, evidence is scarce (Vanguelova *et al.* 2018), and soil carbon loss increases with increasing intensity of the cultivation practice (Creber & Perks 2021).

Summarising recent research, Forest Research reported that trying to establish carbon budgets for woodland creation on peaty soils yielded "variable and inconclusive results", concluding that "*On soils with organic layers <20cm, it is likely that carbon losses arising from cultivation would be reabsorbed by the growing trees within 10-15 years, depending upon the growth rate of the trees; whereas on soils with organic layers > 30cm the time taken for the growing trees to reabsorb released carbon may be over 20 years.*" (Vanguelova, 2021). Follow up Life Cycle Analysis (LCA) modelling by Forest Research and the University of Edinburgh (Creber & Perks, 2021) concluded that reducing cultivation disturbance can reduce the time to net carbon benefit, even for high yielding tree species, on peaty soils.

Recent research on establishing woodlands in the Scottish uplands cast doubt on the assumption that native woodlands planted on peat are positive in respect of soil carbon over decadal timescales (Friggens *et al.*, 2020, Matthews *et al.*, 2020). Friggens *et al.* (2020) recorded a decrease in soil carbon relative to control heather moorland plots after 12 and 39 years in birch woodland on peaty podzols in northeast Scotland; however Armstrong (2020) counselled against extending inferences from the Friggens *et al.* 2020 work, in part because the research conclusions were drawn from results at only one site and the researched native woodland was planted at very high densities - 10,000 and 21,000 stems per hectare, some 6-12 times the norm. Decreasing carbon in topsoil

following reforestation has been recorded in a large-scale reforestation project in the Scottish Highlands (Warner *et al.*, 2021). Whilst soil disturbance from cultivation was considered as a cause of soil carbon loss other potential factors included soil microbial and mycorrhizal community changes, increasing fertility (nitrogen) linked to decomposition, and site variability – tree planting sites favouring drier areas. This work may better represent planned native reforestation in the Scottish Highland (Warmer *et al.*, 2021), in contrast to a controlled experimental study with high-density single species planting on moorland.

Matthews *et al.* (2020) modelled and mapped the potential carbon benefits/debits of planting a range of tree species on different soil types and land classes at a Scottish national level. This study used 1:250000 soil maps, a suite of different forest management types and the Aberdeen University ECOSSE soil carbon model. The modelling showed that the carbon sequestration potential of new afforestation is most effective using high yielding conifer species on the best quality agricultural (arable) land, and least effective when using industrial forestry techniques to establish native woodlands on wet upland peaty soils. A useful next step for this work would be re-running the model with an augmented set of forest practice scenarios. For example, to model the impacts of excluding drainage, using lower impact mounding or flat planting for native woodlands, and establishing trees by natural regeneration, thus avoiding soil disturbance and carbon emissions from cultivation.

Soil carbon research and modelling on Glenmore National Nature Reserve and Rothiemurchus Estate semi-natural pinewoods in the Cairngorms (Ražauskaite *et al.*, 2020) concluded that prolonging forest rotations reduces soil carbon loss. Whilst soil carbon in old growth pine stands (120 years +) was high - soil organic carbon increased with age and lack of disturbance - model simulations indicated that soil carbon, as much as 60%, could be lost through management operations such as felling and replanting, with lowest modelled stocks being in 40-50 year old stands.

4.4 Soil carbon and drainage

Good drainage is effective in achieving rapid forest growth, and Scotland has centuries of expertise in draining peat for forestry (Zehetmayr 1954; Evans *et al.* 2016). Excavators dig ditches 70-100cm deep, 30cm wide at the base, at around 20m spacing, to rapidly remove excess water from wet sites and help to dry peaty soils (Anderson and Peace 2017, Sloan *et al.* 2019). This intensity of upland and forest drainage is particular to the UK and Ireland (Evans *et al.* 2017).

Lowering the water tables of peaty soils leads to soil carbon loss (Vanguelova *et al.* 2018), causing carbon dioxide to be released, and drains to flush particles of organic carbon and dissolved organic carbon (Haddaway *et al.*, 2014) into rivers. The flow of carbon from peat, via drainage ditches, into rivers is important (Liu *et al.* 2019). Organic acids released from drainage and forestry on peaty soils are recognised as a major contributor to acid rivers (Blacklocke 2016, Pickard *et al.* 2021, Jovani-Sancho *et al.* 2021). The presence of conifer plantations can double the quantity of carbon lost from peaty soils compared with un-forested catchments (Williamson *et al.* (2021).

Loss of organic carbon from afforested peaty soils is detrimental to river water quality, river biodiversity, reservoir water treatability, and public health (Freeman *et al.* 2001, Sloan *et al.* 2019, Ritson *et al.* 2014; Williamson *et al.* 2021). Where best practice is adopted, as was done for the river Halladale, forestry operations need not contribute to water borne carbon loss. Shah, Nisbet and Broadmeadow (2021) showed that the Halladale planting scheme, in northern Scotland, did not damage the freshwater ecology. This because some 12-21% of the river catchment was afforested, with no conifers planted within 50m-70m of a river and 5m buffers left at the end of each plough furrow. However, more commonly, intensive planting operates with 2-10m wide riparian-buffers (depending on the width of the water course) and 2m between a ditch and a stream.

Empirical measurements of carbon loss into watercourses are often underestimates because rivers continually de-gas into the atmosphere (Cory *et al.* 2015). Recent estimates of carbon loss from afforested peat range between 1.15 and 5.46 t CO2e per hectare per year (Gregg *et al.* 2021, Jovani-Sancho *et al.* 2021) and up to 9.91 tonnes CO2e per hectare per year (Evans *et al.* 2017). In 2017, the UK government accounted for emissions from peat under conifer plantations as a major contribution to UK peat GHG emissions, reporting this to the IPCC as part of the UK's greenhouse gas emissions inventory (Evans *et al.* 2017). Continued intensive afforestation and replanting of forests on peat (as well as intensive agriculture on peat) was and is releasing stored soil carbon and may not be contributing to UK efforts towards net-zero carbon emissions (e.g., Brown 2020). The debate about whether to use empirical (Tier 2) or modelled (Tier 3) approaches to quantifying emissions in the UK GHG Inventory continues; this is important for policy makers, because the modelled approach gives lower carbon emissions (e.g. Jovani-Sancho *et al.* 2021).

Clearly it is difficult to measure or model large scale environmental data over long timescales however, researchers beyond the UK consider that the main driver of carbon loss from peat is the presence of drainage ditches (Saurich *et al.* 2019, Asmala *et al.* 2019, Evans *et al.* 2021), rather than the presence of any particular land use; Scotland, with its wet climate, undertakes more intensive drainage for forestry than most other countries (Evans *et al.* 2017).

The most recent data suggests that the UK's rivers contain more carbon than the global average, and much of this appears to be coming from forest plantations on drained peat (Williamson *et al.* 2021). It seems that the ditches draining Scotland's peaty plantations are exporting more carbon than we expected.

4.5 Soil carbon and harvesting

Clearfelling and brash removal.

The dominant silvicultural system in Scotland is even aged, plantations, mostly in single species blocks using a 'patch clearfelling' system. Patches can range in size from less than 1 hectare up to 100 hectares; rotation lengths vary from 35 to 50 plus years depending on the yield class (growth rate) of the trees, the site stability and/or the owner's objectives. The system is high intensity and often large scale, which affects carbon dynamics (Xenakis *et al.* 2021).

When clearfelling is done on shallow or deep peats the risk of soil carbon loss is high (Morison *et al.,* 2010) and research has shown that clearfelling reduces soil carbon stocks in shallow peat soils (Vanguelova *et al.* 2019). It is linked to an increase in particulate organic carbon (POC) in stream waters (Ryder *et al.*, 2014; Rogers *et al.*, 2011), and can be followed by increases of dissolved organic carbon in freshwater (O'Driscoll *et al.*, 2016).

In the UK, research for the Scottish Executive (Scottish Executive, 2007) indicated that clearfell harvesting results in carbon loss from increased decomposition rates and accelerated leaching losses of dissolved organic carbon. Harvesting with heavy machinery disturbs the soil and the litter layer (Blanco, 2018; Clarke *et al.*, 2015) and in North Wales, Gupta & DeLuca (2012) reported that below-ground C stocks in clearfelled Sitka spruce plantations on podzolic soils recorded a 50 t Cha^{-1} loss from the organic horizon of mineral soils 7 years after clearfelling; however, some carbon lost from upper layers may leach down the soil profile and be held in deeper mineral layers (Vanguelova *et al.*, 2018).

Clearfell site with peat in water course, Kilfinan, October 2020. Photo: W. McGhee

Xenakis *et al.* (2021) placed flux towers over Sitka spruce clearfell sites on shallow peats in the northeast of England to estimate the sink/source dynamics in comparison to a closed canopy stand and found that annual emissions of circa 7.09tCyr^{-1} from the clearfelled are comparable to uptake (in the mature stand) of 7.05tCyr-1. Two years after restocking the clearfelled area appeared to be acting as a weak source, possibly due to rapid revegetation.

Impacts on soil carbon of leaving or removing residues after clearfelling are inconsistent. Jarvis *et al.* (2009) found that the recovery of soil organic carbon after clearfelling is dependent on minimising soil disturbance and leaving harvesting residues such as brash on site. In contrast, Vanguelova *et al.* (2010, 2019) recorded carbon stocks in peaty gleys in the UK as higher under whole-tree harvesting (WTH) than under stem-only harvesting. Whole tree harvesting involves removing tree and branches to the edge of a site where the trees are processed and brash piled in large heaps. Where brash is left on site, higher mineralisation of peat occurs and Peatland Action (NatureScot)[4] advisors recommend that on peaty sites, brash should be removed where possible to minimise carbon losses and maximise peatland health.

A climateXchange evidence assessment reported that increased CO_2 emissions on peat soils as a result of harvesting are a product of the decomposition of tree roots, harvesting residues and ground vegetation; with higher water tables, CO_2 emissions decrease, CH_4 and N_2O emissions increase, although the interplay between CO_2, CH_4 and N_2O is unclear (Vanguelova *et al.,* 2018).

Shah and Nisbet (2019) note that using specialist felling techniques - skylines and hand felling - can reduce negative impacts of clearfelling on water quality and carbon particle loss through reduced site disturbance.

Thinning and alternative silvicultural systems

Thinning in even aged forests is uncommon on peat soils because of windblow and the use of alternative silvicultural systems in Scotland is rare. Consequently, there is little research on the impact of thinning on soil carbon in a Scottish context, only two studies being referenced in Morison *et al.* (2010).

A meta-analysis on the impacts of forestry practices on soil carbon by Zhang *et al.* (2018) found thinning had no significant effect on soil carbon stocks - heavy thinning decreased soil carbon stocks

[4] https://www.nature.scot/climate-change/nature-based-solutions/**peatland-action**

and light thinning increased soil carbon stocks; short-term increases in soil respiration were reported in thinned broadleaved forests, more so than in coniferous stands.

Results from a continuous cover forestry (CCF) plot in North Wales suggest that CCF could improve soil quality in comparison to even aged clearfelling (Pitman *et al.,* 2011) and could lead to more stable carbon stocks in the litter layer and negligible change in the mineral layer (Jandle *et al.*, 2007). CCF management reduces or removes the need for large scale forest soil disturbance, and it is likely that carbon losses from soils will be less than in an even aged clearfell system thus maximizing forest soil carbon stocks (Stokes and Kerr 2009).

Stump removal results in significant soil disturbance; stump removal from a clearfell site in upland Wales caused large soil carbon losses (Vanguelova *et al.* 2018), disturbing approximately five times the volume of soil compared with trench mounding; the impact on soil carbon is higher in peat soils than mineral soils.

4.6 Soil carbon and restocking

Restocking (replanting) takes place after clearfelling and with some 800,000 hectares of Scotland's existing forests planted on deep and shallow peats (Vanguelova *et al.*, 2016) there is the potential for significant loss of soil carbon through oxidation and removal of the litter layer during operations to prepare clearfell sites for restocking. Site clearance can be by brash raking /windrowing (stacking brash into rows) followed by scarification, mounding, or ripping to provide planting positions for tree seedlings. Ploughing is not commonly used on restock sites due to the presence of stumps.

Trench mounding or spoil ditch digging is an intense form of cultivation employed in restocking. It involves an excavator digging a trench typically following a brashmat (forest brash laid across the soil to facilitate timber extraction) and using the dug material for creating planting mounds as new tree planting positions. When mounding is complete, the excavator may fill up the trenches with ripped stumps and brash back, partly to 'tidy' the site and partly as a Health and Safety measure. The practice increases drainage, resulting in peat drying and cracking, exacerbating the loss of soil carbon. On deep peats and shallow peaty soils, trenching and stump removal can disturb some 75% of the top 30cm of soil (after Bill Raynor, FC soil surveyor, cited in the Woodland Carbon Code 2021[5]).

Sitka spruce restock on deep peat Kilfinan, October 2020. Photo: W. McGhee

4.7 Soil carbon over multiple rotations.

Vanguelova *et al.* (2019) studied carbon stock choronsequence from Kielder Forest in Northumberland on peaty gley soils most of which were drained, deep ploughed, and afforested. Sites included control moorland sites, first rotation forest sites (to age 65 years), clearfelled sites and second rotation sites, where clearfelled sites were mounded or dolloped before restocking. The study is notable for covering a time series of industrial forest production, capturing data on the

[5] Woodland Carbon Code, Version 2.1 https://woodlandcarboncode.org.uk/images/PDFs/Woodland_Carbon_Code_V2.1_March_2021.pdf

three forestry practices under consideration – cultivation, clearfelling and replanting- and it has been key to informing Scottish Forestry guidance on upland cultivation for industrial forests. Soil carbon losses from the peat horizon due to cultivation were described by Vanguelova *et al.* (2019) as '*large but variable'* with approximately 30% of original peat layer carbon stocks lost (94.3tCha^{-1}) over *c.* 30 years (-3.14tCha^{-1}yr^{-1}). This quantum of soil carbon loss is comparable with those reported at Coalburn, also in Kielder Forest, of *c.* -2.8tC ha^{-1}yr^{-1}, and *c.* -3.3tC ha^{-1}yr^{-1} at Harwood Forest, to the east of Kielder Forest (Zerva and Mencuccini, 2005; Mojeremane, W. *et al.* 2012).

Reports from land use scientists and those working for water companies now suggest that forests on peaty soils may be emitting more carbon than originally thought (Evans *et al.* 2017; Gregg *et al.* 2021; Jovani-Sancho *et al.* 2021, Williamson *et al.* 2021). These results contrast with the expectation that forests sequester carbon - forestry soil carbon chronosequences and GHG fluxes show that the carbon gains in above ground biomass in fast growing conifer biomass can outweigh soil carbon losses from forestry practices, especially for rapidly growing trees. Comparing these figures is difficult, partly because forestry moves carbon from one 'pool' to another: the carbon in timber biomass is short-medium term (returned to CO2 when it burns, decays or rots); whereas the carbon in peat may be more stable over long time periods (Smith *et al.* 2007).

4.8 Summary: What we learnt about forestry practice and soil carbon

- Soil carbon research provides a patchy picture of the impacts of forestry practice. This is partly due to the different research methods for measuring the movement of carbon, partly because of the heterogeneity of soil, partly the forms that carbon assumes (aqueous, gaseous and solid) and the different research questions being asked.
- Afforestation of mineral soils on better quality agricultural land increases soil carbon content.
- Peaty soils, deep peats and organo-mineral soils lose carbon when disturbed by cultivation, harvesting and restocking.
- Carbon loss due to cultivation declines with decreasing soil disturbance, ploughing being the most soil disturbing and flat planting with a spade the least.
- Natural regeneration of trees does not disturb soils, but soil carbon loss can still occur after canopy closure owing to biological changes in the soil. However there is little research into this.
- Drainage of peat soils to lower the water table results in enhanced aeration, increasing oxidation, the transport in water of Dissolved Organic Carbon (DOC) and Particulate Organic Carbon (POC) causing losses of carbon.
- Restocking on peat soils using trench mounding increases drainage and causes large scale disturbance, leading to significant loss of carbon.
- Removing brash from clearfell sites reduces mineralisation of soil carbon and soil carbon loss.
- It is unclear at what point carbon sequestration in tree growth balances losses from soil carbon and research is not definitive.
- Focussing on the time to carbon-positive (the date where tree carbon sequestration might exceed loss of soil carbon) has proved unhelpful for peaty soils, because forestry on peat moves carbon from a long-term carbon pool into a short-medium term pool.

5 Professional knowledge

When we asked stakeholders about forestry and carbon science, the most common topic discussed was the existing professional knowledge of foresters. While nobody disputed the fact that disturbing peaty soils results in a release of greenhouse gases, many felt that the science underpinning the forthcoming cultivation guidelines was scarce and delivers mixed messages. Several were taking an active interest in the science and two were involved in commissioning new science by hosting PhD work and consultancy studies on specific sites.

5.1 Professional knowledge

More than published science, most respondents drew on their own knowledge to discuss the science behind cultivation decisions, and the wider aspects of carbon budgets in forestry.

Much of this professional knowledge was directly linked to observation and experience. Respondents provided numerous examples of situations that they had observed, questioned and informed their opinion.

> *I just look at things, I've got that sort of brain [contractor]*
>
> *We see again and again schemes where ploughed trees have established faster with less failure, less man hours, less chemical and less resources at nursery.* [commercial FM company]
>
> *I've learnt from my mistakes. A couple of sites that we windrowed and it was really deep peat; the following year a lot of weeds and vegetation came up. That site would have been better mounded than brash raked* [public sector FM]

> *I had a better understanding of soils at uni, ten years ago. It is not something I use regularly now so it has been pushed out of my memory.* [commercial FM company]

There was generally a high level of confidence in soils knowledge based on vegetation survey skills, but less confidence in knowledge of soil carbon.

> *If we are going to sell ourselves as being green we have got to get it right. If they get the sense you are wrong they will lose faith in you. If you care going to make claims about carbon you better be right. Far better to say "I don't know, I'll find out."* [independent agent]

Stakeholders also highlighted a need to learn more to keep up with changes in the market.

People argued both ways about the evidence for (dis)benefits of ploughing and often drew on their own observations to contrast with the science available to them.

> *So many say we are foregoing yield [if we don't plough]. Is there really that much evidence? We're using genetically improved crops so we're getting so much more yield anyway. The difference between planting on mounded or drained land doesn't affect the investment value.* [independent agent]
>
> *The science is not there – but you can interpret it yourself, the result of ploughing is less water, more oxidation, giving it a nice warm position, faster growth.* [commercial FM company]

Others contrasted their professional knowledge with what they saw as the (misguided) values of others. Again, the arguments supported both sides of the 'to plough or not to plough' debate.

> *Old foresters say the proper way is to plough; we were trying to get the old lecturers to come out and see the mounding. Because they have never seen it.* [contractor]
>
> *I'm become a bit concerned over the last few years that some people are almost fundamentally against plough or almost any kind of ground prep, like religious zeal. I want to make sure the debate stays in science, economics.* [commercial FM company]

5.2 Active engagement with science

Overall there was a strong sense of respect for science and evidence. Most however said that they relied on member organisations (Royal Scottish Forestry Society; Institute of Chartered Foresters; Confederation of Forest Industries) and Forestry Journal to draw their attention to new science, and in particular looked to Forest Research (which publishes regular research updates).

> *One thing I like about the sector is there is no fear of evidence. Because we are sufficiently confident that what we are doing is beneficial. We are not going to get evidence that says stop doing forestry. So bring on the evidence!* [member organisation]

> *Any forester worth their salt is looking at this [research] and asking what is coming next. All professional foresters should be taking the information and asking, "Should I and can I make changes?" Where you can make those changes you should.* [independent agent]

Some felt that the topic of soil carbon was so important that all foresters should be paying close attention. There was a widespread view that if the science indicates practice needs to change, then foresters must change their practice.

> *As a member of the advisory group and being told that soil carbon was an issue I thought I should go away and read about it. So I downloaded as many papers as I could and read probably about two dozen of them, I then realised what a murky world it is. There was very poor data on soils, it was not clearly explained at all, and quite often the conclusions that the researcher made didn't stand scrutiny. So I then thought, hold on, this is very dodgy. [*Commercial FM company*]*
>
> *I really do believe that things should be science-based. But we do have to have the science right.* [independent agent]

At the same time, this level of active interest led to quite a critical attitude to research. Many were familiar with two recent papers in particular and critiqued the way they had been interpreted. In turn scientists have critiqued the critique, in particular noting that Vanguelova *et al.* 2019 is not based on outdated cultivation methods.

I have become incredibly frustrated at the spin that's being put on it [Friggens et al., 2020)], taking research out of context, spinning it for own ends. [independent agent]

It's an interesting paper in its own right, but how you can take a site with no ground prep, low yield class etc. and extrapolate that to all forestry? [different independent agent].

A lot of the research [Vanguelova et al 2019] was in Kielder, deep peat that we wouldn't now be allowed to plant. We couldn't plant those now and we couldn't use those techniques now. I don't think it's fair to compare what we're now allowed to. [commercial FM company]

It was looking at sites where they had done wrong old fashioned things, downhill drains, ploughed, some practices that would never be done now. [members organisation]

Most respondents from all stakeholder groups felt that scientific knowledge was not yet adequate to support decisions about carbon management especially with regard to soils. A particular gap that many highlighted was a perceived disconnect between studies of soil carbon and of the full carbon life cycle through several rotations. The idea of 'time to carbon positive' is considered important. In many respondents' view, focusing only on soil carbon leads to failure to appreciate the value of productive forest creation. In contrast the review of science in this report indicates that the carbon balance of trees is well understood, while that of the soils in forestry much less so.

5.3 Summary: What we learnt about stakeholders' knowledge and science

- Practitioners take a critical interest in the science of soil carbon in forestry.
- Most foresters rate their experience and observation of results in the field, more highly than scientific papers.
- Forest managers generally consider the science to be incomplete in two ways: it has not yet taken into account the combined effects of forestry on soil and above-ground carbon; and it does not consider the cumulative effect over multiple rotations. Many feel that such approaches would support the case for ploughing and rapid initial growth.

6 The policy and standards context

6.1 Regulation of soils

The regulation of soils in Scotland operates in much the same manner as regulation of air and water and can be categorised into three tiers:

1. Legislation and high-level policy.
2. Principles and standards developed by government agencies with input from stakeholders such as land-use and industry bodies and environmental NGOs.
3. Good practice guidance and outreach.

The upper two tiers provide the umbrella framework for administration and management, while the third guides and encourages practitioners to operate in a responsible manner. All aspects are usually underpinned by technical and policy-related research. That is the theory at any rate. In practice, soil has no direct legal framework; instead, soil quality regulation and guidance in Scotland comprise various components providing either direct or indirect protection in relation to a specific impact or function of soil. The result is that several government departments and agencies are involved in the regulation of forest soils, which leads to a particularly complex and fragmented framework.

6.2 Legislation and high-level policy

Neither the UK nor Scotland have overarching soil protection legislation, as is the case in other European countries (e.g., Germany, the Netherlands[1]). Instead, soils legislation has developed in an *ad hoc* fashion in response to issues, with no legal protection for soils.

6.2.1 Legislation

The lack of an EU Framework Directive on soils means that there is no legacy legislation that carries over post-Brexit such as exists for water and biodiversity. The lack of direct overarching soil protection legislation in Scotland may be a reflection of the UK's market-liberal national culture (Prager and McKee, 2015) combined with the absence of an organised community of interest lobbying for good management of forest soils.

Legislation in respect of soils falls into the category of laws that are primarily directed at other issues, such as water, stemming from the European Community (EC)'s Water Framework Directive (WFD) becoming law in Scotland as the Water Environment and Water Services (Scotland) Act 2003 (WEWS Act).

The Water Environment (Controlled Activities) (Scotland) Regulations 2011 – more commonly known as the Controlled Activity Regulations (CAR) – and their further amendments of 2013 and 2017 apply regulatory controls, through General Binding Rules, covering the discharge of water run-off via a surface water drainage system to the water environment. These are directly applicable to forestry practices - cultivation, drainage, and harvesting - which impact on peat through dissolved organic matter or particulate organic matter discharged into watercourses.

6.2.2 High-level policy

There is no single Scottish governmental body responsible for soil or soil carbon. Rather soil is treated differently by different government agencies and departments. Scottish Forestry deals with forest soils and forestry impacts, NatureScot (formerly Scottish Natural Heritage) is concerned with impacts on soil in relation to biodiversity and habitats, the Scottish Environmental Protection Agency (SEPA) becomes involved with soil carbon in relation to the potential impacts on water quality. Apart from a few government and research institutions, the understanding of soil governance is poor and scant attention is paid to the role of soil carbon in strategic forest policy documentation (see next section).

6.2.3 Scotland's Forestry Strategy (2019)

Scotland's Forestry Strategy sets out the Scottish Government's view of Scottish forestry, presents a 50-year vision for Scotland's forests and woodlands and sets out a 10-year framework for action. In terms of the impact of Scottish forestry on soil carbon, and integrating the Government's net zero emissions target, this was an opportunity to flag up the importance of forest soils as carbon stores and outline the way forward in terms of maintaining these stores. However, this opportunity was not taken. Rather, the potential for any negative impacts arising from forest operations, including impacts on soil carbon, is alluded to as a historical issue (page 24) predating the first publication of the UK Forest Standard (UKFS) … "*Many of Scotland's existing forests and woodlands were planted before the formal concept of sustainable forest management was adopted, around 20 years ago. We are therefore still dealing with the impacts of some forestry practices carried out prior to this … These impacts are now being addressed when the forests and woodlands are harvested, so that their redesign and replanting meet the requirements of the UKFS."* This suggests that we no longer have issues relating to 'modern' forest practice and that the standards within the UKFS are sufficient regulation for the forestry sector. However this would not appear to be the case.

6.3 Principles and Standards - The UK Forestry Standard (UKFS)

The UKFS is the reference standard for sustainable forest management (SFM) in the UK and is a code of practice that translates legal requirements, international and national aspirations as well as policy into a set of requirements and guidelines; these are complemented by good practice guidance on relevant operations and topics. It deals with eight interlinking elements – general forestry practice, biodiversity, climate change, historic environment, landscape, people, soil and water – and has three levels of compliance:

1. **Legal requirements** – these are statutory requirements, the contravention of which could lead to prosecution. The word **MUST** is employed in relation to these**.**
2. **Good forestry practice requirements** – these are requirements for SFM that are linked to international criteria and commitments and meet UK and national government policies. The word **SHOULD** is employed for these.
3. **Guidelines** – these provide detailed information for forest owners and managers on how to comply with the UKFS. The word **AVOID** is used for forestry practices that are considered unacceptable.

6.3.1 UKFS direct impact on soils and soil carbon

The UKFS deals with soils under various headings; acidification, contamination, compaction disturbance, erosion, fertility and organic matter and soil carbon guidance can be summarised as follows:

1. **Minimise** the soil disturbance necessary to secure management objectives, particularly on organic (peaty) soils.
2. **Avoid** establishing new forests on soils with peat > 50 cm in depth and on sites that would compromise the hydrology of adjacent bog or wetland habitats.
3. Woodland creation on certain sites where deep peat soils have historically been highly modified **may be considered** if it complies with the relevant country policy.
4. **Consider** the potential impacts of soil disturbance when planning operations involving cultivation, harvesting, drainage and road construction.
5. **Ensure** the removal of forest products from the site, including non-timber products, does not deplete site fertility or soil carbon over the long term and maintains the site potential.

6. **Consider** the balance of benefits for carbon and other ecosystem services before making the decision to restock on soils with peat exceeding 50 cm in depth.

Whilst the UKFS clearly acknowledges the importance of soils as carbon storage in deep peat it does not accord shallow peats any measure of protection or give firm guidance on what to do in respect of restocking. The UKFS states that forest practice may result in "*short-term loss of carbon from the soil until this is replaced as forests grow*". This statement appears to be based on optimistic, and somewhat dated, carbon sequestration and balance figures. Recent research (Vanguelova *et al.*, 2019) suggests that on peaty soils the first 30 years' growth of plantation forest may not sequester or balance the carbon lost because of cultivation.

6.3.2 UKFS indirect impacts

Requirements and guidelines directed at other aspects of forestry activities have an indirect impact on soils and soil carbon, such as those related to water and acidity. Forestry operations affecting water and water quality are regulated under laws stemming from the EU's Water Framework Directive (see the section on legislation above). Breaking these rules can trigger action by Scottish Forestry and/or SEPA.

6.3.3 How well does the UKFS work?

The UKFS is a useful document and forestry practitioners like it because it contains a lot of easy-to-follow guidance in one place. Unlike legislation, it is more directly focused on the practical issues of forestry but has yet to catch up with the government's net zero GHG policy.

A criticism of the UKFS guidance is that it allows foresters too much latitude in their operations – there are too many 'shoulds' and 'avoids', and not enough 'musts' with much left open to interpretation and while there are sanctions for breaching the code – from a warning letter to revocation of a woodland grant scheme contract. In practice these are often no more than a 'slap on the wrist'.

6.3.4 UKFS Compliance Procedures (2018)

Scottish Forestry has developed a set of UKFS compliance procedures, launched in 2018 and designed to deal with breaches of the UKFS in relation to Forest Plans, Felling Permissions, Forestry Grant Scheme contracts and Environmental Impact Assessment (EIA) consented operations or during unapproved operations (e.g., illegal felling).

In theory these procedures equip the regulators with the means to monitor forestry practice: cultivation (in a Forestry Grant Contract), clearfelling (through Felling Licence) and restocking (also a Felling Licence); and where breaches of UKFS guidelines, good practice or legal requirements occur, to act by withholding permissions or payment of grant, requesting repayment of grant, or revoking licences. In practice, this does not happen, in part because Scottish Forestry are understaffed and under-resourced, and are inundated by new planting applications, significant felling licence applications and forest plan reviews. For example, in March 2021 Scottish Forestry suspended new Forestry Grant applications to clear a backlog of casework. No monitoring of UKFS has taken place in Scotland since the Compliance Procedures were published and the online 'bad boys' register of UKFS breaches, which was due to go live in 2019, has never appeared.

6.4 Good practice guidance

Most technical guidance relating to forestry and soil carbon emanates from Scottish Forestry (and previously FCS) and Forest Research, and covers forest practice such as soil cultivation, drainage and harvesting. It feeds into the UKFS as Good Forestry Practice.

There are several well-respected forestry practice guides or technical notes some of which are specifically directed at forestry practice and peat soils. However, most guidance tends to leave specific decisions with the forest manager, e.g. whether to reforest on deep peat after clearfell. This

flexibility, which forest managers like, has been challenged by recent concerns about cultivation of peaty soils and in the case of new planting it has been effectively removed through the new Scottish Forestry cultivation guidance (see next section).

Cultivation for Upland Productive Woodland Creation Sites – Applicants Guidance (March 2021)

Scottish Forestry published "Cultivation for upland productive woodland creation sites: Applicant's Guidance" in 2021, with a "Background Note" based on work by Forest Research and Technical Development Branch. This makes clear that cultivation and drainage of peaty soils of 10cm depth and greater leads to the release of significant amounts of carbon into the atmosphere, and that where more intensive cultivation techniques are used, there is a high likelihood that more carbon dioxide will be emitted than absorbed by the trees for the next few decades. It also affirms that aggressive cultivation techniques such as ploughing run contrary to Scotland's efforts to reach net zero carbon by 2045. The Guidance sets out which cultivation techniques are acceptable on which soil types (Table 1) and concludes ***"that the most appropriate approach is to exclude the use of medium and high disturbance soil cultivation techniques on all organo-mineral soils with an organic layer over 10 cm in depth".***

Table 5 – Caveats of use

Technique	Environmental constraint			
	Soil Carbon Can be used on organo-mineral soils with a peat depth layer 10-50 cm?	Water Management		Forest Stability Can be used on sites with DAMS score ≥ 16?
		Can be used within UKFS buffer areas?	Can be used on moderate or steep slopes?	
Manual screefing	Y	Y	Y	Y
Sub-soiling aka ripping or tining	Y	N	N*	Y
Patch scarification using excavator	Y	N	Y	Y
Inverted mounding	Y	Y	Y	Y
Hinge mounding	Y	Y	Y	Y
Patch scarification using scarifier aka continuous mounding	Y	N	Y	Y
Trench mounding	N**	N	Y	Y
Rotary (helix) ploughing	N	N	N*	N***
Line scarification using disc scarifier	N	N	N*	N***
Shallow ploughing	N	N	N*	N***
Deep ploughing	N	N	N	N

* May be acceptable on moderate slopes where detailed analysis has established soil erosion risk is low and appropriate mitigation and controls are deployed.
** Where an integrated drainage system is put in place drain spoil may be used for mound formation on condition drain intensity does not exceed the minimum level required for successful site establishment.
*** May be acceptable where additional mitigation measures are incorporated within forest design, see Appendix 3 Guidance Rationale – Forest stability.

Table 1. Adapted from the "Cultivation for upland woodland creation sites – Applicant's Guidance" (Scottish Forestry, 2021)

This careful and precautionary piece of forestry good practice guidance has endured a lengthy gestation period (over three years), and has been published in the teeth of objections from the industrial forest sector as represented by CONFOR and the Institute of Chartered Foresters (ICF). The ICF response to the guidance contested the Forest Research findings: ICF accepted that soil cultivation releases carbon, but continued to argue that intensively cultivated fast growing conifers accumulate biomass carbon rapidly enough to offset the soil carbon losses. As noted in previous sections, the soil scientists' response is that soil stores carbon more permanently than timber; the carbon needs to stay in the peat. The arguments continue.

6.5 How practitioners see policy and guidance

To understand attitudes to the changes to the guidance on forest cultivation, our study asked practitioners about their views on forestry policy.

6.5.1 Attitudes to policy mechanisms

The larger FM companies were keen to emphasise their respect for the UKFS and their need to meet that standard. In particular the definition of deep peat as 50 cm was widely accepted.

Forest managers in the private sector emphasised a pragmatic respect for standards and science.

Regulators were less convinced that this attitude is universal, and one cited a report indicating that only five years ago, in south Scotland, only 74% of sites were found to be UKFS compliant. Another regulator pointed out that the UKFS leaves much room for interpretation.

> *People are comfortable with guidance and adhering to it. Having the standard makes life easier.* [commercial FM company]
>
> *If the science says the carbon balance is incredibly important then forestry needs to follow the best practice in order to keep its credentials.* [independent agent]

> *In UKFS all the words are in there but people focus on 'what's the minimum I can get away with'.* [regulator]
>
> *The UKFS just says to minimise ground disturbance to achieve your objectives. But if your objective is to grow SS as quickly and cheaply as possible then ploughing fits that!* [regulator}
>
> *People do contest guidance and there is pushback from the sector. But I don't think it does the industry good if we are ploughing when SEPA have got very good reasons to not plough. We are just opening ourselves up to criticism.* [independent agent]

A degree of tension between their financial goals and regulation was expressed in many remarks from the private sector.

> *We were infuriated. Frustrated. That's how the process makes you feel. We work for the people who have the money and want to make more money; the conservators have to swing far the other way to make sure we end up in the middle.* [commercial FM company]

6.5.2 Carbon policy

Across sectors, stakeholders highlighted net-zero targets as a core policy driver.

> *Carbon is very much flavour of the month in the market. Policy is driven by the aim to become carbon neutral. It's an easy win. We know exactly the cost / ha, forestry sector will deliver it and there we go.* [membership organisation]
>
> *Five years ago we wanted to squeeze the Sitka levels down, now we are focused very much on soil and carbon because the government has declared a climate change emergency* [regulator]
>
> *We are busier than in the last 30 yrs because of woodland creation. Because the grant system now is supporting more woodland …there's political point scoring for their carbon capture.* [Contractor]

Some felt that different standards and practices are expected in the **public sector**. FLS has its own cultivation guidance, but staff noted that the tendency to leave sites fallow for pest control overrides cultivation concerns.

> *The political point scoring for carbon capture is a joke because we've done no maintenance on any Forestry Commission [i.e. FLS] sites this year because they are throwing all the money at woodland creation.* [contractor]
>
> *From the professional point of view we don't pay attention to policy. We're asked to work to keep up with the private sector but we have more and more hoops to jump through (e.g. procurement). It's bureaucracy for bureaucracies sake.* [public sector FM forester]

6.5.3 Effectiveness of policy tools

Scottish Forestry (in its previous incarnation as FCS) had recently reduced the grant payable for new forestry, when the land had been ploughed. Several stakeholders described this as surprisingly ineffectual as a deterrent.

> *I thought it would knock ploughing on the head but it doesn't seem to have done. They still want to plough and claim less per hectare. I must admit I really thought, people always want to claim the highest rate. It just shows how ingrained this ploughing thing is ...* [regulator]

Respondents had a lot to say about the forthcoming Soil Cultivation Guidelines[6]. Regulators saw a need for them but had mixed views on their value. Private sector respondents were less enthusiastic. The main reservations from both sectors related to the scope for interpretation (although some just disliked the idea of them). Regulators wanted the guidelines to leave no room for interpretation. The final version has addressed this need, but as a result has met with opposition from the commercial sector.

The most frequent theme expressed in the private sector was that the guidelines have not yet been published but that they already influence decisions made by woodland officers. This creates the problem for forest management companies and investment advisers that decisions on new planting applications are affected by a document that is both invisible and unclear.

> *The cultivation guidance that we are adhering to is in draft form. There was some argument about that decision made by Scottish Forestry that we have to adhere to guidance even though not published.* [commercial FM company]
>
> *FC started to implement it before it was official, it was forced on us retrospectively, we were held to it even though not it has not yet been rubber stamped.* [commercial FM company]
>
> *It's been forthcoming for a long long time.* [commercial FM company]

At the time of research the guidance had not been finalised, hence the remarks about invisibility. Remarks about lack of clarity relate to the perception that interpretation is left open to the judgement of woodland officers. This, it is argued, means that judgements are unpredictable and

[6] Scottish Forestry (DRAFT 2019). Cultivation for upland productive woodland creation sites: Applicant's Guidance. **:** 26.

subjective. From the private sector perspective, room for interpretation was desirable, but not if that interpretation was in the eyes of the Woodland Officers.

Private sector forest managers in particular feel they have considerably more experience and knowledge than the Woodland Officers, and that they should be allowed to make judgements about the suitability of land for ploughing.

> *The guidance should be there as a guide but not as a bible. It should allow you to interpret in a sensible way on site. If part of your site requires ploughing, there's a place for that.* [independent agent]
>
> *Everybody interprets guidance in different ways. There is a thought that, with some woodland officers, their interpretation is that ploughing is basically a bad thing.* [commercial FM company]
>
> *There are woodland officers who have fetishes about certain things, you end up having to do certain things for certain people. At the same time there isn't categoric guidance about this is soil X and you must do Y.* [commercial FM company]

The need for negotiation is also experienced as a need for extra resources by the regulators.

> *If the guidance was black and white and ploughing was a thing of the past that would be dead simple and you wouldn't need extra people on the ground but because it is open to interpretation you have to spend a lot of time discussing with people and arguing with people. It's a war of attrition …* [regulator]

> *[On one site] the whole of it has been mounded, and that's because we objected to the shallow ploughing, now they have done the mounding, now they are aware and the next time they will know our start point.* [regulator]

One regulatory body felt that this active negotiation was a valuable learning process and was contributing to a shift in practice.

Some felt a document focusing on soil cultivation only, missed the point that (in their view) tree growth compensates for soil carbon loss.

> *I don't find the soil guidance convincing. We should be looking at the broader picture … not just establishment but comparing how quickly trees are established in this situation vs that situation. That is missing.* [commercial FM company]

> *The industry was screaming out for a better steer, to do things in a more sustainable manner. So [the Water Guidelines] were welcomed.*

These concerns contrast sharply with the level of consensus and acceptance of the **Water Guidelines**[7] which were often referred to.

[7] Forestry Commission (2019). Managing forest operations to protect the water environment. Forestry Commission Practice Guide., Forestry Commission, Edinburgh**:** 48 pp.

The UKFS applies to the award of planting grants and felling permissions. However, there is a widespread view that standards are applied more loosely at felling and there is a lack of effective regulation applied at restock. Some saw this as an advantage. Some of the complaints could be addressed by wider understanding of the process.

*Commercial restock is not monitored nor directly regulated. There's less opportunity to drive up good practice. It's much vaguer what is bad practice. [*membership organisation]

Lots of private clients feel that policies are inflexible and are a constraint especially for woodland creation - less so for restock. [commercial FM company]

Both private sector respondents and regulators expressed confusion about the development process, and frustration about the time taken to produce the guidelines.

Part of the issue is that it's been in draft for a few years, I don't know what the hesitation is, it makes it more difficult for us, the hesitation and back and forth. [commercial FM company – respondent who was not on the development group and not aware of the delays requested by his colleagues]

It's maybe down to Scottish Forestry not laying down the law strong enough. [membership organisation]

6.5.4 Resources for implementing policy

Respondents from the private sector complained about the process for approving planting applications, but in addition several recognised that Scottish Forestry is stretched beyond capacity. Some in turn felt that Scottish Forestry was not strict enough.

I'm aware they have gone through a period of change, there are a lot of people coming in. I don't feel the mentoring is there to give them the experience so they are falling back on the rule book. [commercial FM company]

Some in the private sector feel that their knowledge and experience greatly exceeds that of many of the woodland officers who are entrusted with approving woodland creation plans. Some attempted to educate SEPA and FCS (now Scottish Forestry) staff by inviting them on site to see how ground preparation would work.

We need to look at the culture, training, and competence of Scottish Forestry staff. We don't feel we are pulling in the same direction often. [commercial FM company]

Within the forestry sector there is a widely shared view that the regulators should somehow be 'pulling in the same direction' as the private sector. However if they did that, it would leave the sector without checks and balances.

6.6 Summary: what we learnt about the policy context and practitioners' attitudes to policy

- Soils are weakly regulated, soil carbon does not enjoy a high profile with policy makers and regulators, monitoring of forest practice impacts on soils is uncommon and not well resourced.
- Scottish Forestry has acted to mitigate aggressive cultivation techniques on shallow peats.
- Technical guidance documents covering clearfell harvesting, drainage and restocking are dated and in need of revision.
- The UK Forest Standard is a clear and well used primer for practitioners; however, it lacks teeth in respect of outlining the dos and don'ts relating to drainage, clearfell harvesting and restocking on deep and shallow peats.
- Many foresters are simply looking for timely predictable application processes, and welcome transparent settled guidelines. A few feel that their own experience and knowledge is superior to that of regulators, and they should be allowed to vary ground preparation accordingly.
- The commercial sector sometimes portrays the regulatory sector as a nuisance, under-skilled and failing to stand together with colleagues across the profession.
- The UKFS is widely accepted and used as a reference point to support the view that current forestry practice is sustainable. However, regulators pointed to evidence that compliance with the UKFS is significantly lower than would be expected.

Ploughing on peat, Langholm, December 2020. Photo: Christopher Nicholson

7 Conclusions and recommendations

We summarise our conclusions below with recommendations in italics.

1. Forest soils contain the bulk of Scotland's forest carbon.
   Scottish Forestry should highlight the importance of forest soils in the next iteration of Scotland's Forest Strategy and the forest sector should give clear messaging about the importance of keeping carbon in the soil.

2. The science of how forestry affects soil carbon is evolving, patchy and often difficult to interpret, but has developed rapidly during the last two years. Different sectors of science ask different research questions and use different research methodologies.
   Science should fill gaps on:
   - *the impacts of using natural regeneration for establishing and restocking forests; using less intensive silvicultural systems such as CCF, and clearfell harvesting and restocking on peaty soils*;
   - *establishing carbon balances for industrial forests over multiple rotations; modelling native woodland establishment without drainage and mechanical cultivation.*

3. Conifer stands accumulate carbon in the organic layers through needle litter, but repeated disturbance on peaty soils in even-aged clearfell systems, with shortening rotations, poses questions regarding the efficacy of industrial forestry as carbon sinks.
   The industrial sector should place greater emphasis on foresters being soil carbon managers, by a. minimising soil disturbance on peaty soils, b. reducing the scale of clearfell *sites, c. lengthening forest rotations, d. doing early thinning in conifer stands and e. adopting continuous cover forestry.*

4. Whilst there is unanimity regarding the link between forest practice, soil disturbance and GHG emissions, industrial forestry interests argue that short term GHG emissions are acceptable if trees grow rapidly. Focus on the time-to-carbon positive (the date where carbon sequestration by tree growth might exceed loss of soil carbon due to site management) is unhelpful for peat soils, because the fate of carbon in softwood timber products is variable and often temporary, whereas peat is a permanent carbon store.
   Consensus amongst regulators, scientists and local communities is now building that *forest practice should adopt the precautionary principle and minimise peaty soil disturbance, i.e., discourage restocking on peat soils*.

5. Cultivating and planting mineral soils is far more carbon efficient than planting peaty soils, so *afforesting mineral soils, rather than peaty soils, should become a higher priority*.

6. Peatland drains are losing more carbon than expected, so *the excavation of drains and ditches in peaty soils for cultivation, clearfelling and restocking should be phased out.*

7. The commercial sector is primarily driven by investors seeking a high return on investment. This incentivises practices with externalised costs (such as soil damage). Most foresters are however motivated by good forest management, and some see it as their professional responsibility to guide investors in this direction. *A stronger focus on 'good forestry' in external portrayals of the sector would help the public understand professional values.*

8. Above all, the private sector interests want stability in regulatory guidance. Whilst new cultivation guidance has recently been adopted, its development and acceptance was a painful and protracted process, in which parts of the private sector resisted change and questioned soil/climate science. At the same time, government science proceeds very cautiously.
   If government and the regulator are to provide a lead in working towards NetZero, they need to

adopt a clearer and more proactive approach to resourcing science and adopting the precautionary principle. Terminology within the guidance on soils should be changed such that "shoulds" become "musts".

9. In the debates about forestry, soil carbon and regulation, most attention has focused on new afforestation. Harvesting and restocking of existing sites, many of which are on deep peat which would be excluded from new afforestation, has eluded scrutiny. The forestry sector, both public and private, is making some adjustments to practice on its own account, but widely recognises that this is a problematic area which needs research, agreement on good practice, and regulation. Using natural regeneration to establish new forests or restock recently felled stands results in minimal soil disturbance.
   Natural regeneration should be encouraged both for forest establishment and for restocking.

10. The public sector is struggling to deliver adequate supervision of on-site forest practice because of increased workload and staff shortages.
   Regulators need more resource and increased budget for guidance, monitoring and regulation and to speed up good applications.

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