Regenerative forestry

The Evidence

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Image: R. Walter

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Introduction

Across the world, forests are facing the twin challenges of a rapidly changing climate and biodiversity loss, as well as pressures from competing land uses such as farming and development. The UK's forests are just as vulnerable to these threats, which is why the Soil Association is calling for a new vision for the future of the UK's forests – both as a land use and as a set of forestry management practices.

There are extrinsic reasons why forestry needs to change: the climate crisis is deepening and all living ecosystems will be badly affected; the ecological crisis requires a landscape-scale response to restore natural systems; both farming and forestry need to develop greater resilience to anticipated shocks and disturbances; and in the UK we have limited land with which to balance these demands.

There are also intrinsic factors which make some current forestry practices questionable: we need to adapt silviculture to changing site conditions, and to sequester and store more carbon. How long can we continue to plant and harvest on the same site before essential nutrients are depleted? We need to reverse biodiversity decline in our forests. We need to engage greater public understanding and support for forestry to facilitate more trees in our landscapes.

Regenerative forestry sets UK forests up to face the future. It delivers a positive carbon balance, increases biodiversity, supports forestry livelihoods and creates spaces for people to enjoy nature. Equally important, it helps forests build resilience to the risks and pressures they face from a changing climate and societal needs.

This publication explores in depth why the UK needs a new paradigm for sustainable forestry, to develop as a regenerative land practice. It looks at the need for change from three perspectives: for the climate, for nature and for people, and seeks to understand the connections between them.

It serves as the evidence base to Regenerative Forestry - *forestry and forests for the future* which sets out the current state of UK forestry and forests and describes the Soil Association's vision of, and principles for, regenerative forestry.

Image: R. Shaw

02

Forestry **fit for the climate**

Trees and forests are being mobilised in the battle against climate change and there has been a surge of interest in tree planting. Whilst this attention is welcome, simply relying on trees to offset carbon emitted elsewhere is misguided. Trees cannot save us from climate chaos – only drastic cuts in greenhouse gas (GHG) emissions can do that. The UK's current greenhouse gas emissions are 452 MtCO2e per year and forests sequester 18 MtCO2e of this (4%). In 2050 the country's 'residual' emissions should be 90 MtCO2e and expanded forests could then sequester 22 MtCO2e (24%).[1]

The reasons behind forests' current limited ability to sequester more carbon – and some possible alternative practices – are explored below.

Forest soils

Despite being the very foundation of civilisations and a crucial tool in tackling the climate crisis, soils are hidden from view in forests and suffer from serious neglect. Soils provide the fertile ground from which all life springs, and play a key role in storing carbon, which circulates in dynamic exchange between air, trees, mycorrhizal networks, soil, soil organisms and water. Healthy soils sequester carbon, but where soils are degraded, poor quality or eroded they release it into the atmosphere.

Saving our Soils – in forests as well as on farms

The Soil Association has long championed the fundamental importance of soils for sustaining life, and supports The Sustainable Soil Alliance's aim to restore Britain's deteriorating soil.[2] Today, healthy and fertile soil is recognised as the foundation for farming and forestry.[3,4]

Our recent report, Saving our Soils[5] identified seven ways to maintain and improve soil health on farms. They are all broadly applicable to forestry:

- **monitor soil health**
- **increase levels of plant and animal matter in the soil**
- **reduce tillage and chemicals**
- **maintain protective cover**
- **bring more trees into farmland**
- **reduce compaction**
- **use long and diverse crop rotations**

In Wales

50%

of soil carbon held in deep peat and organo-mineral soils, despite covering only 20% of the land

The soil provides a wide range of functions, including provision of water, nutrients and anchorage, buffering of flood water and pollutants, sequestration of carbon, habitat for biodiversity, and holds an historical archive.[6,7] The UK Forestry Standard gives some prominence to soils as one of seven elements of Sustainable Forest Management (along with biodiversity, climate change, historic environment, landscape, people and water), and Forestry Commission Guidelines underline the importance of protecting soils from physical, chemical and biological damage, whilst maintaining fertility.

Yet care for the soil has not historically been the guiding principle of UK forestry. Although, soils in the UK's few remaining Ancient Semi-Natural Woodlands (ASNW) have generally not been cultivated this is not the case for more recently planted forests.

The UK's model for increasing forest cover and timber production has – until recently – been largely based on afforestation on upland soils, pioneered by the Forestry Commission in the early 20th century and also practiced widely by private afforestation companies from the 1960s to the 1980s. Whereas pre-WW2 afforestation tended to match the tree to the soil, post-war planting tended to modify the soil to the tree, aided by advances in technology.

These upland sites have often suffered from waterlogging, poor aeration, low nutrients, heather cover and sometimes an ironpan. Whilst it is possible for trees to grow on such sites, the industrial model required predictable establishment within short timeframes followed by high outputs, so site improvements were deemed necessary. This included drainage, subsoiling, scarifying, mounding and ploughing. In particular, ploughing deep and shallow peat soils had the effect of mixing organic with mineral soil horizons to release nutrients, whilst burying heather provided vegetation control, a raised planting position and drainage, all in one operation. Site cultivation was so widely used in the post-war period that it became the norm in the UK, unlike in the rest of Europe. As a result, avoiding cultivation has not been properly considered.[8]

After cultivation, sites were planted with one or two species (e.g. Sitka spruce, Lodgepole pine) in monocultural blocks. The legacy of this is that single species account for 55% of British stands to this day.[9] At the end of an economic rotation, a stand was clearfelled, exposing soils to the elements and causing further disturbance, followed by cultivation of the site again for restocking. This system of Clearfell / Restock (CF/R) accounts for the overwhelming majority of UK production forest management by both government and private owners. Whilst this has enabled successful afforestation and harvesting, it is increasingly recognised that such disturbances can damage the soil[6] and are unsustainable in the long-term. For the healthy functioning of the soil and for the continued storage of carbon, soil disturbance must be minimised, and this aspect of forestry practice must be revisited.[10]

Peat and organo-mineral forest soils

Peat soils are generally over 50% organic (plant) matter and more than 40-50cm deep. Organo-mineral soils (shallow peat) have a surface horizon rich in organic matter (>20%)[11,12] and are less than 40cm deep (in England and Wales), overlying rock or mineral horizons. In Scotland an organo-mineral soil can be up to 50cm deep. Soils deeper than this are classed as deep peat.

Organo-mineral soils are generally found in the uplands of north and west England, throughout much of Wales, the Highlands and Southern Uplands of Scotland, and the uplands of Northern Ireland.[13] Organo-mineral soils are important for biodiversity, with almost 25% of them in England and Wales under SSSI designations for their specialist biodiversity.

Peat and organo-mineral soils hold by far the most carbon of any terrestrial habitat. In Wales[11] mineral soils cover 80% of the land and hold about 50% of the soil carbon; whilst deep peat and organo-mineral soils cover 20% of the land yet hold the other 50% of soil carbon. Organic and organo-mineral soils make up half the land area of Scotland and Northern Ireland.[13]

The UK Forestry Standard includes a specific assumption against planting on deep peat. When cultivated and drained, peaty soils are at particular risk of losing carbon through drying out and oxidising. Restocking such sites after clearfell also requires careful consideration[14] (of soil type, peat depth, area, slope and tree growth).

Where loss of carbon is likely to be significant, removing forest and restoring to peatland is recommended. Scottish Forestry has now strengthened its afforestation policy,[15] citing research showing that "ploughing on soils with an organic layer greater than 10cm represented a significant risk of soil carbon emissions and may mean the soil does not begin to sequester carbon for another 20 years or more."

The greatest impacts of forestry on soils occur by physical disturbance during drainage, planting and harvesting, with risks of soil erosion, compaction, nutrient removal and soil water changes. Soils can be especially vulnerable to erosion where they are on steep slopes, when vegetation is removed leaving soil exposed and when compaction leads to increased surface runoff.

Increased soil temperatures (from exposure to the sun) can accelerate the decomposition of roots and litter. Drainage, in preparation for restocking, dries the soil, increasing decomposition and carbon release. Mounding, to prepare the planting position, disturbs soil leading to oxidation and release of CO_2. Organo-mineral soils often occur in mosaics with deep peat, and forestry on the former can influence adjacent deep peat where they are hydrologically linked.

Broadleaved woodlands have been found[11] to provide the most ecosystem services on organo-mineral soils (ahead of conifers, grassland, heath and cropland), with particular benefits to wildlife, soil/air/water quality, recreation and beauty.

Forests and carbon dynamics

Measuring carbon in living systems is complicated. Roughly half of the dry mass of trees is carbon. Whilst forestry is mostly interested in the stemwood for timber, much of the tree's mass is in branches, foliage, roots, especially in broadleaves. As well the carbon stored in trees, other above- and below-ground carbon stores must be considered. These include carbon in ground vegetation, leaf and needle litter; the various soil horizons (organic, topsoil and sub-soil); proportion of peat; mycorrhizal fungi and carbon in water. Measuring carbon requires considering how all these elements behave during disturbance and over different timescales and what happens to the carbon once it has left the forest (e.g. as timber). Carbon is a dynamic substance in constant flux in the air, plants, soil and water, and should be seen as a cycle rather than as a permanent fixture. There is considerable variation in the evidence, but there is broad consensus on the following observations.

Carbon sequestration and storage

Measuring carbon in living systems is complicated.

Need to know

Carbon sequestration is the incorporation of atmospheric CO_2 into plant tissue and soils, often expressed for forests in tonnes of carbon dioxide per hectare per year (tCO_2/ha/yr).

Carbon storage, or stock, is the amount of carbon in a system, often expressed for forests as tonnes of carbon per ha (tC/ha). 1 tonne of carbon = 3.67 tonnes of CO_2

A comprehensive analysis[16] of British forests found that carbon stocks in trees, litter and soil averaged about 308 tC/ha, with about 75% of this in the soil, though some of these forests were planted on carbon-rich peat soils.[17] Another comparison[18] found that organo-mineral soils hold about 321 tC/ha, with over 50% of soil carbon held in the top 15cm. This is 30% less than the carbon held in peat soils (448 tC/ha) but double that of mineral soils (133-155 tC/ha).

In southwest England, carbon stocks have been estimated[19] for various land uses, including both vegetation and soil. Broadleaved forest had 273 tC/ha, with 40% in vegetation and 60% as soil organic carbon. Mixed forest 202 tC/ha; conifer forest 166 tC/ha; natural grassland 124 tC/ha; moors & heathland 110 tC/ha; and peat bogs 583tC/ha. Peat bogs contain by far the most carbon of terrestrial habitats, twice as much as broadleaved woodland, which itself has twice as much carbon as natural grasslands and pastures. When considering changing one land use to another, it is very important to bear these figures in mind, as well as the biodiversity associated with each habitat.

A forest's period of greatest carbon sequestration is during the period of greatest biomass increment. After this, carbon stocks continue to increase, but at a slower rate.[16,20] So even more mature forests can still accumulate carbon. Ancient woodlands, for example, are expected to more than double their carbon stocks over the next 100 years.[21]

Natural England's figures for carbon stocks are as high as 354 tC/ha for 100-year-old mixed native woodland on mineral soil to 1m depth. Such a wood would also sequester about 7 tCO2/ha/yr (averaged over its life), compared with about 14 tCO2/ha/yr for the same wood at 30 years old. Arable conversion to low input grassland would sequester about 1.6 tCO2/ha/yr, whilst semi-natural grassland is considered to have reached carbon saturation.[17]

354
tC/ha for 100-year-old mixed native woodland on mineral soils to 1m depth

Image: R. Shaw

Carbon stocks
273
tC/ha, from Broadleaved forest

Carbon stocks
202
tC/ha, from mixed forest

Carbon stocks
166
tC/ha, from conifer forest

Natural England recommends creating new native broadleaved woodland for an effective carbon sink, comparable to non-native conifers, and with added benefits for biodiversity. Broadleaved woodlands, even under clearfell silviculture (which is unusual), have much longer rotations than conifers managed for timber production (about 100 years as opposed to 50 years), so their carbon stocks will be held secure for longer over the critical decades ahead. Natural England also recognises that higher carbon sequestration can be achieved under fast-growing non-native conifer forests in the wetter climates of the west and uplands, but only with suitable site conditions.

Carbon Brief compared[1] a high-yielding conifer forest (75% Sitka spruce, 10% Douglas fir and Scots pine, 5% native broadleaves, 10% open space) with productive native broadleaves (90% broadleaves, 10% open space). The authors of the study found that, at age 30, the broadleaves had sequestered 18,000 tCO2e compared with the conifers, which sequestered over 23,000 tCO2e (some 28% more).

A study[22] of commercial afforestation for climate change mitigation modelled variables of species, timber harvesting, product substitution, and biomass and confirmed that forest growth rate is the most important determinant of cumulative mitigation over a 100-year timescale. The study found, unsurprisingly, that planting solely high-yielding Sitka spruce achieves the best mitigation, more than twice as much as broadleaved woodland. The study only focused on GHG mitigation, and did not consider soils and biodiversity, nor any significant risks to monocultures. However, the authors did argue for the rapid deployment of both commercial forests and semi-natural forests, and for mixed-species forests under sustainable forest management delivering wood products and other ecosystem services.

Planting trees to sequester carbon in this way seems an obvious strategy, but requires careful consideration of the soils, the existing vegetation and land-use, the species chosen, the objectives and management, the harvesting (or not) of timber, the fate of the harvested wood products, and the timescale. Modelling[23] shows that afforestation on a range of soils using low yield-class trees results in carbon reduction (biomass + soils) over 20 years, is close to break-even at 40 years, and only sequesters modest amounts after 80 years.

As some planting practices cause significant soil disturbance, afforestation sites initially lose carbon via the soil before they recoup the losses via the timber and achieve a positive net carbon balance. Planting and harvesting conifers has been found to cause substantial loss of soil carbon from organo-mineral soils during the first rotation. Loss of carbon from peat soil decomposition under forestry has been estimated at 9.9 tCO2/ha/yr.[24] But if soils receive minimal disturbance and tree productivity (i.e. carbon capture) is high, there may be no significant change in soil carbon over two rotations, with early losses from peat layers compensated by later gains in the litter and forest floor layers.[25,26] In fact, a second rotation of Sitka spruce may contribute large amounts of leaf litter absent from alternative land uses and contribute to soil carbon recovery. It is not clear what happens beyond two rotations or 100 years. Organo-mineral soils can lose carbon much faster than they gain it, so if we wish to maximise carbon storage in the crucial coming decades, losing soil carbon under the first rotation may not be acceptable.

The impact of broadleaved woodland afforestation on organo-mineral soil carbon has not been widely studied. A comparison with conifer would need to consider lower soil disturbance at planting, slower growth (and therefore carbon sequestration) and longer rotations (or no harvesting at all). One study in

Scotland[27] found that total carbon (tree + soil carbon) had declined by 12% under planted birch at age 25 compared with heather moorland, though growth of the birch was poor and patchy. At age 39 the birch had accumulated more carbon in the trees to offset the carbon losses from the soil, and mostly returned to similar overall carbon stocks as the unplanted heather.[28]

Tree planting can achieve a positive carbon balance if soil carbon is retained undisturbed at establishment and felling, if atmospheric carbon is sequestered by fast-growing trees, and if carbon is retained in those trees and/or in harvested wood products.

Productive conifer forests generate most of our homegrown timber, which locks up carbon in harvested wood products (HWP). Timber is increasingly recognised as an important low-carbon (or even negative-carbon) material to replace carbon-intensive concrete, cement and steel in construction. These HWP may be transitory, like paper and card, medium term, such as fencing and panels, or long term, for example in buildings.[29] One study of a forest's timber component (assuming neutral soil carbon effect) estimated the carbon benefit of a forest in Scotland at 723 tCO2/ha over 100 years, or 7.3 tCO2/ha/yr. This was compared with net greenhouse gas emissions from upland farming of 1 to 8 tCO2/ha/yr.[30]

Soils and carbon under clearfell/restock (CF/R)

Most forestry for timber production in the UK is managed under the Clearfell / Restock system: trees are planted, thinned where possible, clearfelled at the end of their economic rotation, then the area is replanted again. The effects of this forestry practice on soils have been well documented. Conifers trap pollutants from the air and transfer them to the soil and surface water,[31] producing a more acid humus, leading to podzolic soils where base minerals are leached from upper soil layers, causing soil acidification. Forest streams can have higher acidity and aluminium levels, leading to lower diversity of invertebrates and fewer fish.

Forest soils are particularly vulnerable to disturbance during clearfelling. The greater the intensity of harvesting, the greater the risk of losing nitrogen, phosphorus and potassium from the site.[32,33] Heavy harvesting equipment can cause soil compaction on up to 10% of the site.[34] Removal of the protective forest canopy can cause exposure to rain and sun, leading to soil erosion and disruption to soil micro-organisms.

Clearfelling has been found to reduce soil carbon by over 11%, with the greatest losses in organic horizons. This loss can take over 75 years to recover in mineral soils.[35] Soils lose carbon following clearfelling due to reduced inputs from litter and increased decomposition. The impacts of clearfelling can be reduced by extending rotations, careful harvesting, retaining residues, and minimising soil disturbance.[36]

Harvesting sometimes removes brash from the forest for biomass fuel (whole tree harvesting). Generally the more brash that is removed, the greater the loss of soil carbon, whilst removing the timber only has little effect.[36,37] Removing stumps from any peat soil results in high loss of carbon but may not significantly affect mineral soils.[36]

Many conifer forests were established on peaty soils, and so the choice at clearfell (regarding carbon) is whether to restock with another crop of trees or restore the site back to peatland. If the next rotation of forestry is low-yielding (yield class 8 or less), then there will be a net loss of carbon.[24] In such cases, the Scottish Government supports peatland restoration.[14] Replacement with low-disturbance semi-wooded native habitats may limit carbon loss whilst improving biodiversity.

Soils and carbon under continuous cover forestry (CCF)

Intensive forestry practice on very poor soils and organic soils is clearly damaging. However, on other sites a canopy of trees

is helpful to forest soils as it moderates the impacts of sun, rain and drought, all factors which are forecast to intensify this century.[38]

Nitrogen fluxes are moderated by restructuring closed canopy conifer stands. A more diverse forest with a wider range of species, including broadleaves, will help reduce pollutant capture from the air and thereby the risk of acidification.[6] CCF also helps mitigate nitrate leaching by avoiding sudden large disturbance events and by retaining a young growing component in the stand to take up available nitrate released from adjacent felled areas.[39]

The UK Forestry Standard recommends increasing the resilience of the forest by increasing its diversity: including tree species, genetics within species, stand structure and age structure. More varied silviculture and alternatives to clearfell can achieve this resilience, plus greater provision of veteran trees, understorey, open space and natural regeneration. Minimising soil exposure and cultivation will also conserve soil carbon stocks. Natural Resources Wales recognise the role of structural diversity and lower impact silvicultural systems in reducing the risk of soil erosion.[40]

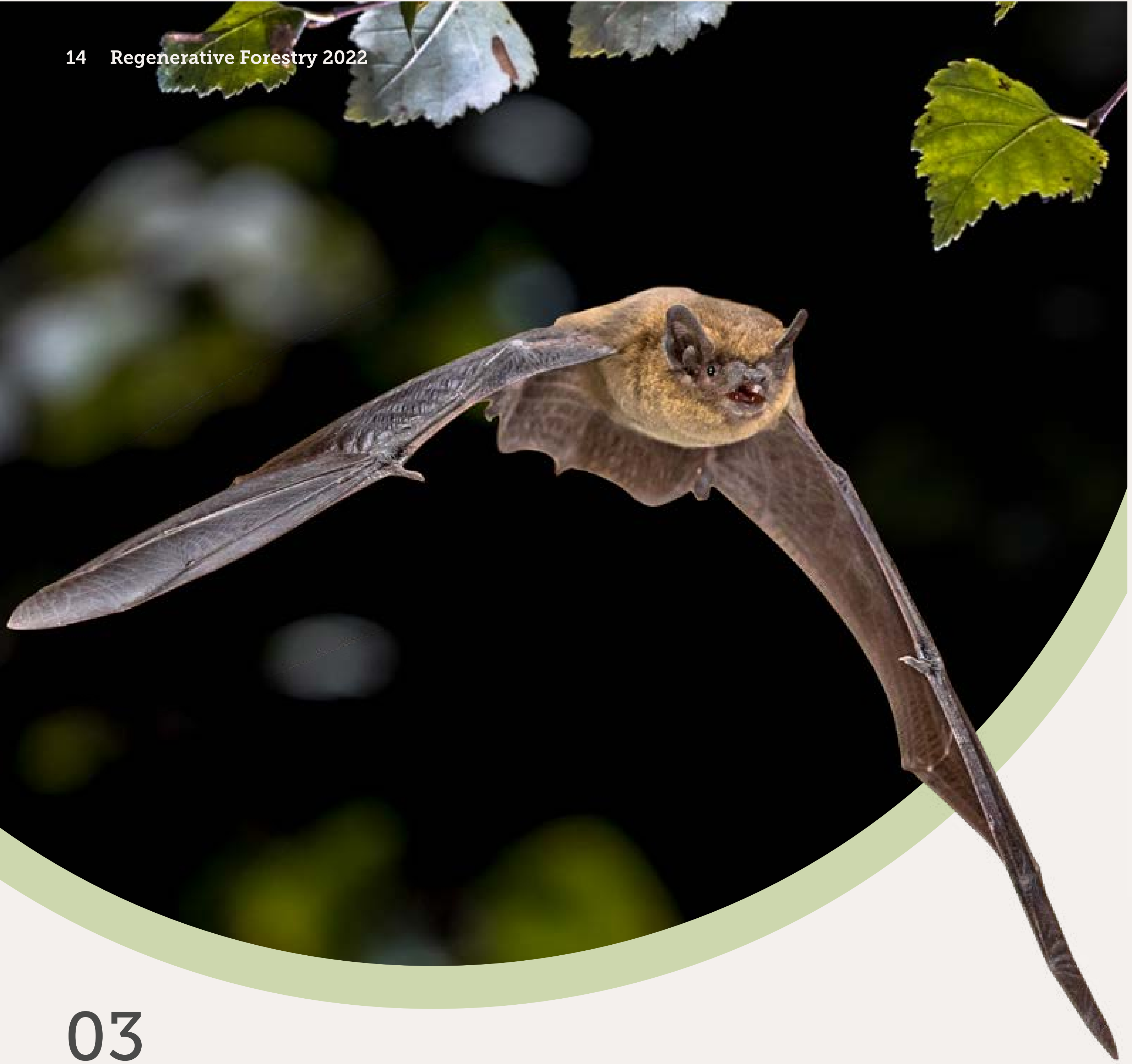
Many studies have found that transformation of even-aged stands to CCF is advisable for the resilience of forest soils,[41] and can improve their carbon storage.[16,42] During harvesting, the higher the canopy retention, the lower the loss of carbon and biodiversity. Retaining old growth phases and deadwood can also increase carbon storage.[44]

Carbon in rewilded and non-intervention forests

One study that is often cited claims that 'restoring natural forest is the best way to remove atmospheric carbon,' and that natural forests are 40 times better than plantations at storing carbon.[45] However, this study is focused on the tropics and sub-tropics and assumes a 10-year rotation of eucalyptus or acacia, with low assumptions for harvested wood product lifespans, so it is not directly applicable to UK conditions.

Rewilding Britain estimates[46] that although the early scrub stages of naturally regenerating forest only sequester 2.2 tCO2/ha/yr, this rises to 8.8 tCO2/ha/yr after 30 years, then 15.0 tCO2/ha/yr thereafter. Rewilding approaches sometimes embrace not only natural regeneration of trees, but also grazing livestock as part of the natural ecology. At Knepp Estate in Sussex, for example, there has been considerable growth of tree cover in the southern block, but this has been quite slow and patchy, partly because of the interactions of the animals. This means it is not that efficient for woodland establishment and therefore carbon sequestration.[47]

A similar approach is pro-forestation – allowing existing forests to grow to their full ecological potential. This requires no additional land, no intervention, and claims to provide a range of other ecological benefits.[48] Whilst mature forests do continue to sequester carbon, and this is a cheap and effective method of doing so, UK forests also tend to lack diversity. Therefore, management interventions are widely supported as a means to improve their biodiversity.



03

Forestry fit for nature

Ancient Semi-Natural Woodland (ASNW) is the UK's most species-rich terrestrial habitat and, although it cannot be recreated, the closer forests mimic such long-term and diverse conditions, the greater their biodiversity value. Because planted forests form a significant proportion of all UK forests, it is critical that they are managed to contribute to the regeneration of biodiversity in the wider landscape.

Nature in decline

Despite a continual increase in wooded area over the last 100 years, woodland biodiversity is in decline.[49] This shows that our new woods are not providing adequate natural habitat, either because they have limited diversity (e.g. non-native conifer) or because they have not had time to develop a complex vegetational structure, which can take a century or more.

Biodiversity in native woodland

The Forestry Commission's 2020 report on Woodland Ecological Condition[50] reveals not only the poor state of the UK's forests, but how they got there. Compared to a benchmark of ASNW in good condition, only 7% of native woodland and 1% of non-native stands (mostly conifers) are in favourable condition; 92% and 95% are in intermediate condition and 1% and 5% are in unfavourable condition respectively. Britain's forests were fragmented long ago, and old trees were removed along with deadwood. More recently grazing livestock, invasive species and pests and diseases have further contributed to poor condition.

Measuring different biological indicators in native woodlands, another study[49] found a marked decline in ground flora species richness (between 1971 and 2001), especially for woodland specialists. This correlates with a lack of intervention and deer management across the landscape, leading to woods becoming older and darker, which favours deadwood and shade-loving biodiversity rather than the ground flora and open habitat communities.

The State of Nature 2019 report[51] notes a 13% fall in average species abundance and 15% of species threatened with extinction from the UK. The authors agree that nature in woodland is under particular pressure from lack of management and overgrazing by deer, and they identify recreational disturbance and nitrogen pollution as additional pressures. Numbers of specialist woodland birds fell by 25% from 1970 to 2017 and woodland butterfly populations have fallen by 50% since 1990.

Despite the area of forest increasing, woodland species are generally in decline. The Woodland Trust suggests[21] this is because much of the increased area is comprised of non-native trees. Existing native woodlands are isolated and in poor condition, and many trees have been lost from the wider landscape outside woods. There is also the factor of time. New native woods have not had time to develop more natural, complex vegetation structure of higher biodiversity value, which can take 80 to 160 years.[52]

There are arguments in favour of, and against, silvicultural intervention in woods. Lady Park Wood was already a high forest ancient woodland when it was designated as a minimal intervention woodland experiment in 1944. Since then, it has been left to grow increasingly shady, which has led to the decline of butterflies and vascular plants. However, species groups that depend on large trees and dead wood may have gained. On balance it seems that regular silvicultural intervention can better maintain the existing biodiversity whilst also controlling invasive species.[53]

There are also strong ecological arguments for non-intervention in woodland. A damp and structurally complex habitat has been found to support more biodiversity.[54] Late-successional species that live and feed on dead plant material tend to be rarer and therefore of more ecological value. Much forest biodiversity associated with rides, open ground and coppicing is open habitat biodiversity, exploiting opportunities in woodlands because intensification of agriculture has decreased opportunities elsewhere. It is therefore also important to conserve old-growth features where they occur, and to leave some woods undisturbed.

Biodiversity in planted forests

Planted conifer forests in the UK have been undergoing restructuring for the last 20 years to improve their diversity, but they still suffer from a number of ecological disadvantages. Such forests usually consist of non-native tree species, often isolated in the landscape, limited to a few species and age classes, which are then periodically disturbed by clearfelling. As such, they can lack any meaningful connection to the wider landscape ecology, have low diversity of habitats and niches, and fail to develop long-term environmental conditions for forest biodiversity.[55]

Despite this, 20th century conifer forests have developed over the decades. They are less prone to waterlogging and can have soils with a deep humus-rich horizon and fungal communities, which creates sheltered conditions and soils suitable for a wider range of trees and forests in future[32]

A 2003 overview of the biodiversity in Britain's planted forests[56] recorded the situation as the authors found it, and suggested ways to improve it. The key message, just as relevant today, for almost all categories of biodiversity was to increase diversity of age class (including extending rotation length); of species (including more native broadleaves); provide more open space and linkage; and more deadwood. More diversity of management was also recommended, with more continuous cover management and natural regeneration. The need for more non-intervention areas close to semi-natural woodland was identified. Long-term retentions and open space were particularly important for invertebrates, as were deadwood and wet areas. Because some birds thrive in early successional forest and others in mature conifer stands, diversity of management is important, including clearfells where appropriate. A variety of stand sizes and shapes will create lots of edge habitat beneficial to wildlife.

One study claimed[57] that in terms of overall species-richness there is no significant difference between Sitka spruce and native pinewood stands (in the uplands), and Norway spruce and native oak stands (in the lowlands). However, these findings include some legacies from previous wooded land uses and proximity to other woodland.[58] The report also concludes that "our findings suggest that exotics are not better *per se* for biodiversity than native trees, and the latter should always be encouraged where conservation objectives are important."

Confor has also made the case for biodiversity in productive forests.[59] It highlights the fact that, whilst planted forests already support a surprising richness of biodiversity, the more diversity of species, structure, habitat, light and shade, and age range, the more beneficial these forests become.

The British Ecological Society welcomes[60] Confor's integration of commercial and conservation management, acknowledging that it could benefit biodiversity. However, it challenges the portrayal of commercial forests as biodiversity-supporting habitats. It also points out that benefits for individual species are not the same as benefits for assemblages of species, nor for underlying functional processes. Native forests support different plant and animal assemblages and for many species non-native conifers are not a suitable surrogate.

An assessment[61] of the UK's 'Atlantic spruce forests' concludes that:

> "The forests are increasing in biodiversity value, albeit of a distinct and different nature to that of native woodland or the open habitats that they replaced; whether the overall balance is judged positive or negative depends on the values placed on particular species or assemblages."

Forestry based on permanence and diversity

The long history of forest loss in the UK means that the level of biodiversity that they could support is unknown. This makes it difficult to set a goal for increasing levels, although it is clear that they *must* be increased from the current very low baseline. What is known, is that more biodiversity increases forest resilience. How to increase biodiversity is the focus of the next section.

Biodiversity and resilience

A recent review of resilience in British forests[32,38,62,63] highlighted the key role of biodiversity in supporting a forest's ability to cope with change and recover from disturbance. Forests need biodiversity in the genetic variation within each tree species, in a wide variety of different tree species, and in the structural diversity of the stand; underpinned by biodiversity in the soil and in the wider forest. Planted conifer forests tend to lack this diversity and the resilience it affords, leaving them vulnerable to pests and disease, especially when under stress.

A healthy soil is fundamental to improving diversity. In mixed conifer and broadleaved forests, the presence of broadleaved litter promotes the breakdown of cold and unaerated conifer needle litter and allows mycorrhizal fungi to help trees tap water and nutrients, defend against pathogens, protect roots, and store carbon. It is equally important to protect the soil in ancient woodland, meaning that most high-impact forest operations should take place in the drier months.

Mixed stands have been found to be as productive overall as monocultures[64,65] especially on poor soils,[66,67,68] whilst providing more ecosystem services and being more resistant to pests and diseases. Diversifying tree species and stand structure will also allow the forest to occupy and benefit from more of the available ecological niches, making better use of light and resources and increasing both the cycling and retention of nutrients.

Stand development in conifer forests could lead to two broad 'future natural' forest types: warm temperate lowland forest with European high forest species, and cool temperate upland forest with North American productive species. Re-assembling components of the forest ecosystem in this way would help to adapt impoverished plantations into 'naturalistic' stands better suited to the challenges ahead.

New afforestation (and restock after clearfell) would seek to establish stands that make full productive use of the site and are adapted to future conditions, including pioneer species (birch, pine), shade tolerant understorey species (hornbeam, beech, lime, western red cedar, western hemlock) and long-lived emergent timber species (Douglas fir, oak, beech).

mycorrhizal fungal networks transport carbon, water, nitrogen, phosphorus, micronutrients, stress chemicals and allelo-chemicals between plants

Mycorrhizal fungi

Mycorrhizal fungi have long been recognised for their symbiotic relationship with tree roots, but the role of mycorrhizal fungal networks in forest ecology is only now being more widely appreciated. These networks transport carbon, water, nitrogen, phosphorus, micronutrients, stress chemicals and allelo-chemicals between plants of the same and different species, across distances in the tens of metres and over time periods of hours to days. A single fungus can span hundreds of hectares of forest.[69]

Research on Douglas fir in Canada revealed that a few large 'hub' trees had the greatest number of fungal connections and were supporting the young seedlings and saplings growing nearby.[70] The hub trees also appeared to recognise their offspring and favour them with nutrients and water via the mycorrhizal network.[71] Measuring the effects of different harvesting intensities, researchers found seedling regeneration was highest in the uncut control and 60% retention stands and lowest in the 30% retention and clearcut stands, and most of this regeneration occurred within 15m of a hub tree.[72] This suggests that a selection of hub trees should be retained during felling to nurture the next generation.

Mycorrhizal fungi are damaged by clearfelling, so alternatives are being assessed. In Scandinavia, CCF was found to maintain soil communities of mycorrhizal fungi and soil chemistry similar to natural unmanaged stands.[73] In the UK, mycorrhizal fungi have been found to spread from ancient woodland to adjacent long rotation stands, to connect and expand ecological networks in a fragmented landscape.[74]

The implications of mycorrhizal networks for forestry practice are profound: a forest is far more than the trees – it is a community of life. In order to 'preserve the integrity, stability and beauty of the biotic community'[75] human interventions in forests need rethinking. The more we understand and work with these collaborative networks, the more we can support the functional ecology of the forest.

Continuous cover forestry and biodiversity

CCF provides biodiversity benefits whilst producing timber. However, there are trade-offs between a productive and a more natural forest, which must be considered when making decisions about land use.

The 'naturalness' of forests can be considered in terms of species, structure and processes,[76] with more natural forests having a greater diversity of species (and of genetics within species), of stand structures, and of ecological disturbances and processes. The CCF approach scores better than Clearfell/Restock (CF/R) on most of these indicators, but not all.[42]

CCF tends to have greater tree species diversity, which can benefit both biodiversity and production. For example, the growth of Douglas fir stands in Canada declined by half with the 'weeding out' of birch, which were actually supporting the fir via mycorrhizal networks, rather than competing for resources as had been feared.[71] By using natural regeneration, CCF also favours greater genetic diversity within each species. Trees naturally possess high genetic diversity and allowing the conservation and expression of this through natural regeneration is a key factor in forest resilience and productivity.[38,77]

An increase in harvesting intensity has been correlated with a reduction in ecosystem services, including species diversity and richness, and carbon stocks.[43] The structure of CCF stands differ most obviously from single age and more closed canopy stands, and this is where much of the biodiversity gain can be found. The greater range of vertical structure and niches is beneficial for bats and some birds of conservation concern (compared to low intervention ASNW),[78,79] and for the abundance of moths, though not species richness (compared to clearfell).[80]

Another benefit of diverse structure is in the control of pests and diseases, such as weevil and bark beetle.[81] Clearfelling a stand offers a feast of cut stumps for the pine weevil to breed and feed. Limiting the concentration of cut stumps and offering alternative food sources avoids an epidemic of weevils, and natural regeneration under CCF can be established without the need for chemical protection.[82]

Ecological processes such as disturbance regimes are essential to understanding forest biodiversity, and operate from the scale of the individual tree to a group, a stand, a forest and a landscape. Forests are structures that constantly evolve, with multiple organisms in different stages of development. It is this diversity of process that generates diversity of life.

At the level of the stand, CCF clearly offers far greater diversity than either an even-aged forest or an unmanaged woodland: there are gaps with regeneration, middle-aged clumps, and mature trees retained for timber, seed and biodiversity. But at the level of the forest, CF/R offers a range of habitats from open ground after clearfell, through thicket, to a degree of mature forest at the end of rotation. The mature phase of CF/R is usually curtailed by clearfell, though some areas are retained in accordance with UKFS and UKWAS.

Across a landscape, the range of forest types, processes and disturbance must be considered, to identify the most benefits. How much should be scrubland, early successional forest, intimate diverse forest, mature forest, old-growth non-intervention?[83] For example, a landscape with both CF/R and CCF seems to favour optimal bird richness and species abundance in the uplands;[84] and protecting 5-10% of forest as 'retention' is considered a minimum for positive ecological response, with more retention providing greater benefits.[85] The size of each forest also has a major influence on its biodiversity, with larger forests offering greater environmental heterogeneity and more ecological niches, and thus supporting a greater range of woodland species.[86] A report on soils[87] found that landscape diversity of farmland, forestry and urban green infrastructures strongly influences biodiversity, the water cycle and soil erosion. it also found that forest soil health is influenced by the naturalness of species composition and management practices, including disturbance by clearfelling.

More forests in a landscape and better connecting habitats such as hedges, also improve woodland biodiversity and resilience, though this may be at the expense of open ground biodiversity. It is important to confront these trade-offs and make informed decisions about land use.

'Build it and they will come' - allowing natural processes to unfold, will generate much higher levels of biodiversity

Nature-based solutions

It is increasingly recognised that tackling climate change and biodiversity must happen in collaboration to maximise benefits and meet social needs,[88] and forests are well placed to contribute to this multi-benefit approach.

The British Ecological Society proposes nature-based solutions (NbS), which combines actions addressing climate change, biodiversity and social agendas.[89] It suggests adapting forests for climate change by increasing genetic and species diversity, by controlling pests and diseases and by improving structure of new woodlands. It states that improving biodiversity value can be achieved by bringing neglected native woodlands back into management, with limited harvesting to create structurally diverse canopies of benefit to ground flora and tree regeneration. However, old trees and deadwood should be retained for their immense value to woodland specialist species. It also suggests increasing native woodland cover and linking ASNW, and limiting afforestation for timber production from non-native conifer species to low-biodiversity grassland (avoiding both species-rich grassland and peaty soils). Investing in NbS would also create employment whilst benefitting people in the long-term. It has been calculated that for every £1 spent on afforestation, a further £2.79 is returned in economic and social benefits.[90]

Another recent example of NbS is Kew Gardens' *Ten golden rules for reforestation to optimize carbon sequestration, biodiversity recovery and livelihood benefits.*[91] Here, the stress is on the importance of genetic variability, natural regeneration and mixed native species, as well as involving local communities and adapting management as projects proceed.

Rewilding is popular amongst conservationists as a strategy for restoring biodiversity, with support for naturalistic grazing and farmland abandonment. Reintroduction of beavers and pine martens is especially favoured.[92] CCF can facilitate rewilding initiatives through its use of natural forest processes and accommodation of wildlife, in particular in buffer zones around core rewilded areas.[93] A key lesson from rewilding at Knepp Estate is 'build it and they will come' – simply allowing natural processes to unfold will generate much higher levels of biodiversity, often of quite unexpected species.[94]

Some may ask whether these measures for biodiversity in productive forests are affordable. The current appetite for increasing forest cover across the UK provides an opportunity to answer the real question – can we afford not to change, given the urgency of our situation?

04 Forestry fit for people

Whilst opinions vary over the merits of different types of forest and forestry practice, most commentators agree that the UK timber sector has been a major success story over recent decades. The maturing and harvesting of the substantial new forest resource established in the 20th century has attracted significant investment in harvesting, processing and innovative product development.

As well as the UK forest resource supporting peoples' livelihoods, it also speaks to people's growing concerns about environmental issues (ranked the 3rd most important issue facing people in England during the covid pandemic, after health and the economy[95]). The fate of trees even occasionally hit the headlines, such as opposition to the felling of street trees in Sheffield, and the enthusiasm for planting shown by political parties at the 2019 General Election.

This increased interest in trees and forests is significant, because there are proposals for massive changes in the UK landscape to combat the climate and nature emergencies, including many more trees and forests, more intervention in existing forests and closer integration with farming. This will only succeed with public support, stakeholder engagement, and a trained and skilled forestry workforce.

The forestry sector in the UK economy

Forestry accounts for 13% of UK land use, contributes Gross Value Added (GVA) of £2.55bn to the economy (0.13%), employs 16,000 in forestry and about 27,000 in primary processing (0.13% of UK employment), supplies 19% of our timber needs and sequesters some 20 million tCO_2 per year.[96,97,98]

Agriculture accounts for 72% of UK land use, contributes GVA of about £10bn (0.5%), employs 476,000 people (1.4%), provides over 60% of our food needs, and emits about 46 million tCO2equivalent per year (10% of our GHG emissions).[99,100]

Our land-based industries (whether forestry or farming), despite being based on the vast majority of UK land, are economically insignificant under current valuations. They also vary hugely in their greenhouse gas balances. How we value land, productivity, carbon and ecosystem services could radically change these valuations.[101]

Forests account for **13%** of UK land use

Forestry contributes gross value added (GVA) of **£2.55bn** to the economy (0.13%)

Forests sequester **20m** tCO_2 per year

A natural capital approach

These anomalies can be addressed with natural capital accounting. For example, a study in Dorset[102] found that when ecosystem services were properly accounted for, rural land uses were about 10 times more valuable than under conventional accounting. Agriculture and forestry occupy similar areas of Dorset to the national average, and notionally represent about 1% of the county's economy and employment. However, the local environment actually contributes £1.5bn of GVA per year in ecosystem services and supports about 30,000 jobs, representing 8-10% of the county's economic output and employment.

The study then modelled scenarios to 2050, including a high level of habitat restoration with less agriculture, more calcareous grassland and heathland, and broadleaved woodland increased from 6% to 20% cover. By investing in natural capital and improving the extent and condition of semi-natural habitats under this scenario, the existing benefits can be increased still further, with GVA up 5% and 25,000 more jobs. For comparison, under conventional economic assessment, such changes result in a small loss of GVA – in other words, there is no further economic benefit from increased industrial exploitation of nature.

This is confirmed by another study,[103] which found that the private benefits of exploiting natural resources are outweighed by the wider social costs of doing so. The non-market benefits of nature conservation are especially high for forests and increase with a rising social cost of carbon. The report concludes that any further changes away from nature, towards human-modified uses, will cost society more than it would gain from such moves.

Another study of afforestation on marginal grazing land[104] found that comparing timber with food did not produce much difference in value, but when natural capital values for carbon, air quality, and flood risk prevention were considered, the planting option was far more valuable. When recreation was added (with permissive access), the values grew still further.

A productive multi-purpose newly planted forest on former grazed hill land in the Scottish Borders was assessed for its natural capital.[105] Whilst timber values were high, biodiversity values were estimated at nearly three times higher (over 50 years) and carbon at nearly four times higher. Such analyses can guide planning and design, make the case for grant schemes and attract investment. The NFU is concerned that afforestation permanently reduces the capital value of agricultural land,[106] but by these measures the Natural Capital value would rise considerably.

In Finland, forests were assessed[107] for their 'social performance' using values for economic, social, environmental and resilience indicators across a range of management types, from conventional CF/R to mixed objective, to CCF. Social performance increased with greater forest diversity, with CCF management scoring best overall. One interesting feature of the study was that lower discount rates favoured better social performance. This is not altogether surprising, as high discount rates favour cashing in assets as soon as possible, with less regard for the long term.

Although conventional accounting might not favour investment in biodiversity or ecosystems, a wider consideration of the benefits shows that it makes economic sense, as well as being vital for restoring depleted wildlife and addressing climate change. The forestry sector will need substantial investment to deliver better management of existing forests and rapid establishment of new forests.

The England Tree Action Plan intends for more timber used in the UK to be homegrown

Forest industry employment and training

The Royal Forestry Society found[108] that employment in forestry grew significantly between 2010 and 2017, probably because of strong timber prices and increased management and harvesting. However, there are still skill and capacity gaps across the whole sector, with shortages of skilled machine drivers, chainsaw fellers and tree planters especially acute. There has also been a decline in forestry courses in higher education, with a resulting lack of forestry professionals as reported by the Institute of Chartered Foresters. [109] The England Trees Action Plan[110] envisages a skilled workforce: forestry and arboriculture will be important sources of jobs and revenue, particularly in neglected rural areas. Training will be available via Kickstart, the Green Recovery Challenge Fund, the National Skills Fund, apprenticeships, T Levels, and a new Forestry Skills Action Plan. The plan also intends for more timber used in the UK to be home grown, strengthening the domestic supply chain. The plan is funded by over £500m of the £640m Nature for Climate Fund. Whilst welcome, this is just 1.7% of the £28.8 billion earmarked for the National Roads Fund.[111]

There is a broad coalition of support for a wider 'National Nature Service' to provide over 10,000 jobs in nature and conservation as part of a post-pandemic green recovery.[112,113] This idea was first suggested by the RSA Food, Farming & Countryside Commission, of which the Soil Association was a member.[114]

Forest economics

The UK's unique history of afforestation did not only create a distinctive planted conifer resource, but also a bespoke method of accounting. Until 1988, the tax system permitted switching schedules to avoid payments on both incomes and expenditures. As such, it favoured separate periods of costs (planting) and revenues (felling) and helped establish Clearfell / Restock as the dominant forest management regime.[115] CCF simply did not fit this economic model.

CCF transformation

Although up to half of the UK's conifer plantations could be suitable for adoption of CCF,[116] uptake has been slow, probably because it does not appear to fit well with the streamlined industrial model by which our productive planted forests were created.[117] Only about 5-10% of UK conifer planted forests are managed under CCF[116] although in FC forests it is reported in over 10%.[118]

Given the current management of productive forest stands, any change to alternative management will involve a period of transformation, and much has been written on this subject.[42,119,120,121] As well as the silvicultural challenges, there will need to be significant changes in forest production and economics. Orthodoxy and subsidy have been identified as key constraints for forestry:

> "The fundamental problem in British forestry is that it must compete with other land uses that have become the norm, which are supported by greater public subsidy".[122]

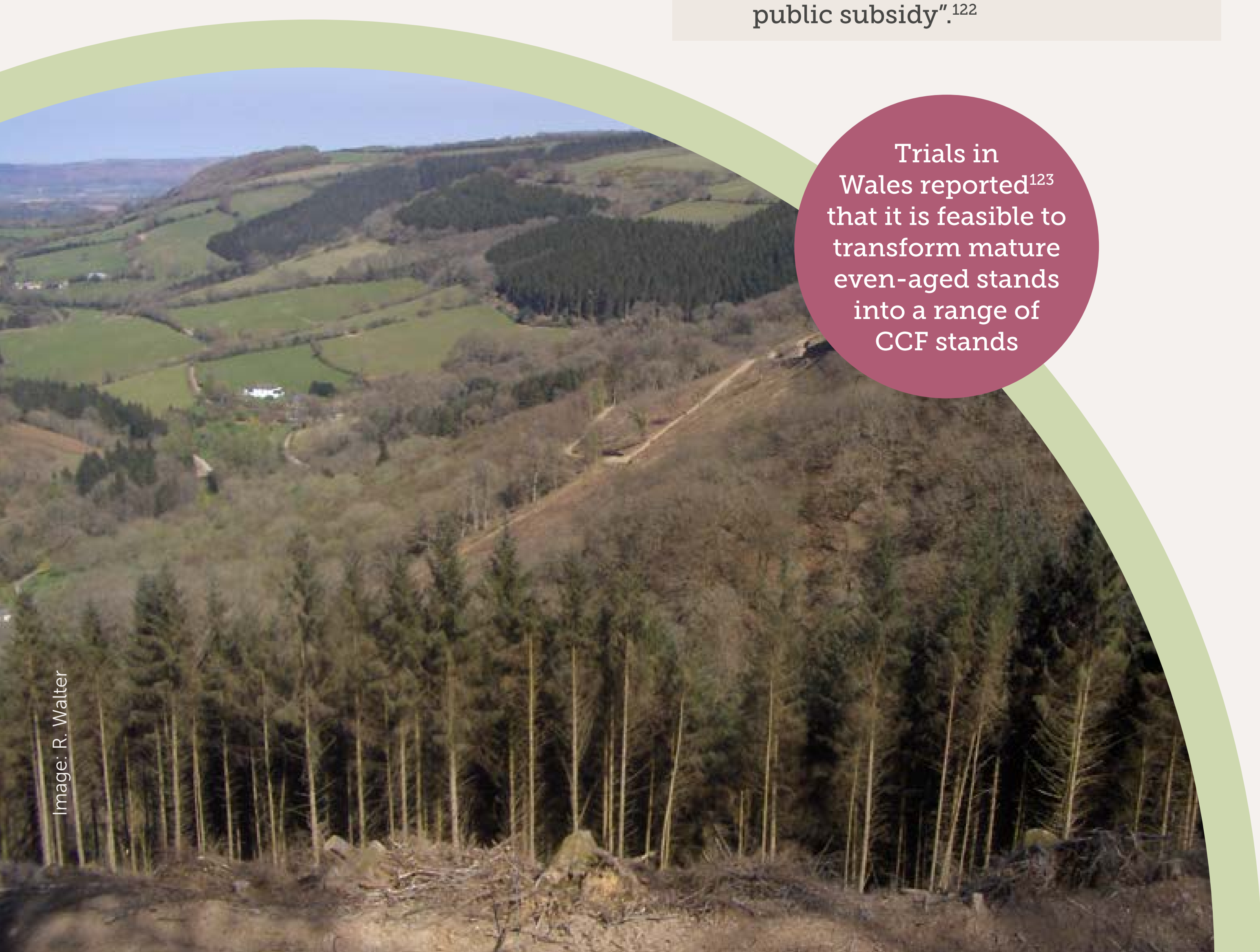


Image: R. Walter

Trials in Wales reported[123] that it is feasible to transform mature even-aged stands into a range of CCF stands

Image: R. Walter

Clearfell/Restock has become the dominant forest management regime

This disparity is particularly felt as a barrier to afforestation, but it is also an issue for forest management. The tax schemes of the 1980s may have gone, but the CF/R model is still certainly the norm.

Early thinnings under CCF remove poor quality stems of all sizes, not just small trees, so harvested volume tends to be higher than conventional thinning.[121] In later thinnings, removals are focused on the larger trees which have reached target diameter, leaving the smaller trees to grow on, again resulting in higher volumes. With no end of rotation felling, the yield of timber thereafter is in theory continuous.

Introducing CCF to upland even-aged forests has been considered problematic because of wind stability.[117] Yet a 20-year trial of CCF methods in Sitka spruce in Wales reported[123] that it is feasible to transform mature even-aged stands into a range of CCF stands, including uniform shelterwood, strip shelterwood and group shelterwood. Underplanting of shade-tolerant species was also successful. Practice has shown that CCF principles are simple and adaptive. Thinning patterns for transformation can be graduated through the stand to suit site conditions and wind events, maximising both site and individual tree potential.[124]

Despite all this, the mainstream forestry sector has been resistant to widespread adoption of CCF. Foresters often perceive it to be overly complex and unsuitable, especially for upland sites. The timber processing sector is also resistant, because it has invested in mills with tight specifications that deem larger, better-quality stems as 'oversize'. The processing sector is undergoing vertical integration to secure supplies in a volatile rising market, which means that it will grow trees that fit its mills, where it owns forests.

However, the impacts on timber assortments from any significant transformation to CCF could be forecast and with timber as the material of choice for a low carbon economy, and with an expanding forestry resource in the UK, there will be time and opportunities for further investments and adaptation of current infrastructure.

CCF economics

CCF produces a steady yield of forest produce that generates earlier returns, a stable cash yield, higher prices for larger and better quality logs, and a growing capital value. One of the main economic savings of CCF is on establishment costs through use of natural regeneration. This has attracted the attention of investors in Ireland, who are advocating CCF for long-term investment, with comparable (if not better) returns than conventional forestry, as well as reduced environmental impacts and greater resilience to climate change.[125,126]

People and forests

The British public loves trees and forests but appears to have less love for – and understanding of – forestry practice. Trees and forests inhabit the public realm, even when they are growing on private land. They are big, enduring, visible components of our shared space and as such people develop feelings of admiration, joy, familiarity, love for them. It is these accumulated values, as well as the wildlife, which can be lost when trees are felled.

Public opinions of forestry

Surveys consistently show that people like trees and forests, appreciate their value for wildlife, understand their role in mitigating climate change, and would like to see many more in the landscape.[127] A study in southern Scotland found strong support for more land dedicated both to wild nature and timber production.[128] Adapting landscapes as ecological networks can be seen as an opportunity rather than a constraint.[129]

Commercial forestry with a focus on timber values can be perceived as neglecting other values of nature, culture and society.[130] A clearfelled site can be shocking, and the brash and deadwood left for nature can, ironically, make it look even worse.[59] A more integrated approach, embracing more environmental and social values, would greatly improve public perception of forestry, and there are many outstanding examples of this happening. Forestry England has long pioneered multi-purpose forestry with a strong recreational element in Moors Valley (Dorset), Dalby (North Yorkshire) and Kielder Forest (Northumberland).[131] Here, planted forests have been repurposed for a range of public activities and have proved very popular.

It is not just broadleaved woodland that attracts visitors, but also mature conifer managed for diversity. However, there appear to be few lay advocates for most upland conifer forests, managed via CF/R, outside the mainstream forestry sector.

Public perceptions of CCF

Public perceptions of forests across Europe were tested[132] across five management intensities, four phases of development (young to old) and three species types (conifer, mixed, broadleaved). Surprisingly, the greatest contribution to recreational value was not tree species but the phase of development: the older the stand, the more people liked it. In Britain, there was a slight preference for broadleaved stands, and a strong preference for forest reserves, close-to-nature and combined objective management over even-aged forests or Short Rotation Forestry (SRF). Long term retention and low impact silviculture of stands with broadleaves and/or conifers appears to be most popular.

In Wales, CCF has been recognised as the management system to provide the most attractive and diverse forests, both within the forest and the wider landscape; to this end, at high profile recreational sites, clearfelling has been deemed the option of 'last resort.

Clearfelling should only be used 'as a last resort' at high profile recreational centres.[40] Clearly, then, CCF is the most appropriate management practice to deliver these preferences, and many managers are already applying it.[133]

Image: R. Walter

05 Learning from pioneers and neighbours

Alternative forest practices such as continuous cover and close to nature forestry have long been established across Europe, and there are some inspiring pioneers in the UK.

European models

Pro Silva was founded in 1989 to promote forest use based on natural processes, thereby reducing ecological and economic risks.[134] It champions integrated forest management for resilience and sustainability across 25 countries.

Association Futaie Irrégulière (AFI) research CCF practice with an emphasis on permanently irregular forests and has established a research network across Europe.[135] AFI initially focused on broadleaved stands, but now includes a range of forest types, including conifers. Its periodic measurements of growing stock have been collated into powerful indicators of forest performance.

UK pioneers

The Continuous Cover Forestry Group (CCFG), formed in 1991, is a member of Pro Silva. It promotes the transformation of even-aged planted conifer forests to structurally, visually and biologically diverse woodlands.[136] There is a strong focus on maintaining permanent growing stock and the sustainable production of quality timber from cyclical interventions. The group offers site visits, research, workshops and training and has been highly influential in UK forestry.

The Irregular Silviculture Network (ISN) is an English-speaking branch of AFI.[137] Its focus is on the actual performance of the forest stand, rather than what the yield tables suggest. As such, basal area across forest components and increments over time are critical parameters that guide management. The aim is to recruit suitable stems into the main stand and distribute increment onto the best stems, harvesting mature trees at their maximum value.

A unique experiment in CCF has recently concluded on the **Tavistock Estate** in Devon.[138] Using the Bradford-Hutt system, even-aged conifer stands have been transformed to CCF using a series of strictly ordered small-coup fellings. The grid pattern ensured continuity of forest canopy with good access for operations. The result is a mixed-species stand with uneven-aged structure, meeting current requirements for resilience. The costs of this unusual method are estimated to be similar to conventional forestry on level ground, but higher for steep ground.

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