UK Parliament POST

POSTNOTE

Number 636 January 2021

Woodland Creation

Large-scale woodland creation is being promoted internationally to mitigate climate change. It can also supply other benefits, such as improving biodiversity, air and water quality. This POSTnote summarises key factors influencing how much carbon is taken up by woodland, the different objectives of woodland creation, constraints to increasing UK tree cover and different finance options.

Overview

- Creating new woodland is widely agreed to be necessary for the UK to meet its 2050 net zero greenhouse gas emissions target.
- All woodlands have the potential to take up and store CO_2, produce timber, enhance biodiversity and deliver other benefits, including recreation and reduced flooding.
- The amount of CO_2 taken up and other benefits or negative effects of woodland creation depend on where and how woodland is established, tree species present, site conditions and management.
- Constraints on woodland creation include economic viability, land tenure, cultural values, permanence of land use change and environmental sensitivities.
- Incentives for woodland creation include government grants and carbon payments. Support could be increased through private finance for multiple environmental benefits.

Background

In July 2019, the UK legislated for a target of net zero national GHG emissions by 2050 (PN-594).[1] Analyses by the UK's independent Climate Change Committee (CCC) indicate that greenhouse gas removal (GGR) will be needed alongside rapid emissions reduction to reach this target (PN-618, PN-549).[2,3] Growing trees draw carbon dioxide (CO_2) from the atmosphere through photosynthesis and store some of this carbon in wood and in the soil; a process known as carbon sequestration.[4,5] Although there are concerns it could distract from emissions reduction,[6–8] increasing tree cover is one of the few proven GGR methods,[4,5,9,10] and can deliver other benefits.

The UK has lost much of its historic forests and associated range of habitats,[11] and the UK's 13% tree cover is well below the European average of 37%.[12,13] The CCC has recommended increasing UK tree cover from 13% to 18%, improving woodland management and adopting agroforestry to contribute to the UK's net zero target.[3] This could annually sequester 15 million tonnes of CO_2-equivalent GHGs ($MtCO_2e$/year) by 2050.[3] The devolved administrations have their own woodland creation targets, strategies and grant schemes (Box 1). The UK Government has an overarching commitment to create 30,000 hectares (ha) of woodland per year by 2025,[14,15] up from 13,660 ha in 2019–2020.[12] If achieved, the commitments in Box 1 would create a total of 26,900 ha of woodland in 2025.

Sequestering carbon with trees

The 'carbon stock' is the total amount of carbon stored on the land in plants and soil at a given time. A woodland is a 'carbon sink' when it is overall removing and storing (sequestering) carbon from the atmosphere (i.e. GGR), whereas a 'carbon source' transfers carbon to the atmosphere on balance.[16] In most instances, woodland growth on UK farmland will act as a carbon sink, increasing the carbon stock on the land by a finite amount over several decades.[17] The rate of sink will be initially slow when trees are young, goes through a rapid phase, and then tails off as the woodland reaches maturity.[4]

Site conditions

On average across global temperate regions, 60% of woodland carbon is in the soil,[18] although this varies greatly. The impact of woodland creation on soil carbon stocks depends on the existing amount of soil carbon and the level of ground disturbance caused by tree establishment (Box 2).[19]

The Parliamentary Office of Science and Technology, Westminster, London SW1A 0AA
02072192840 **post@parliament.uk** **post.parliament.uk** **@POST_UK**

Box 1: Tree planting targets and grants

- **England.** 2340 ha of woodland was planted in 2019–20.[12] Funding is available from the Countryside Stewardship scheme.[20] The UK Government's 25 Year Environment Plan goals require woodland creation,[21] with relevant provisions in the Agriculture Act 2020 and Environment Bill 2020 (CBP-8702, CBP-8824). A planting target is expected and the Government announced funding for 6000 ha/year of woodland creation until 2025 in the March 2020 Budget,[22] with further support through the Environmental Land Management scheme from 2024.[23,24]
- **Scotland.** 11,050 ha of woodland was planted in 2019–2020,[12] with a target of 18,000 ha/year by 2024–2025.[25] Funding is available through the Forestry Grant Scheme.[26] The rate of tree planting has increased from 4760 ha in 2016–17 when the Mackinnon report was published.[27]
- **Wales.** 80 ha of woodland was planted in 2019–20.[12] There is a target of 2000 ha/year from 2020,[28] with funding available through the Glastir scheme.[29]
- **Northern Ireland.** 200 ha of woodland was planted in 2019–20.[12] Target of 900 ha/year from 2020 to 2030,[30] with funding through the Forest Expansion Scheme.[31]

The timing of when woodland becomes a net carbon sink depends on tree growth, productivity and soil carbon,[17,32] which in turn are influenced by site fertility and climate.[33]

Long-term management and end use

If woodland is retained in a landscape, individual trees keep on growing and sequestering carbon. This is broadly cancelled out by some trees dying as the woodland ages,[34] but carbon in dead wood and soils can build up on a centuries timescale in old-growth forests.[35] The average carbon stock depends on the frequency and severity of disturbances such as fires, storms, droughts, pests and diseases that result in tree death or damage (and temporary carbon losses).[4,17] Although mature woodland has a finite stock, it can continue to store carbon and deliver other benefits (Box 3).[36]

Harvested wood products

Some of the carbon sequestered in trees can be removed from woodland in harvested wood products (HWPs). Along with soil disturbance caused by felling operations,[32] this reduces the woodland's carbon stock until trees regrow.[16] Reforestation of recently deforested sites ultimately only restores the carbon stock previously lost and does not mitigate ongoing GHG emissions.[6] However, some uses of HWPs may contribute to emissions reduction:

- **Fencing, packaging, pallets**. These have a relatively short lifespan,[37] but manufacturing such products from other materials may be more emissions-intensive.[17,38]
- **Construction**. Wood can replace fossil fuel intensive materials such as steel.[39–41] Under 20% of UK HWPs are used in construction,[37] but is increasing, in part through use of resilient engineered products like cross-laminated timber.[38,42]
- **Bioenergy**. The emissions mitigation benefits of wood bioenergy are contested,[17] but bioenergy with carbon capture and storage (BECCS) is predicted to play a major role in climate change mitigation (PN-618).[2]

HWPs are only a temporary carbon store; carbon will be released when the wood decays.[16,17] However, on a timescale of decades, increasing long-term timber use in buildings can increase net carbon sequestration as the woodland regrows.[16] This will reach a limit once new HWPs start replacing earlier wood products that have reached their end of life.[17,52] As 80% of wood used in the UK is imported,[53] increasing domestic production could also reduce transport and overseas land use emissions.[8]

Box 2: Influence of trees on soil carbon

Soil organic carbon (SOC) usually increases in woodland on non-peat soils, due to the addition of leaf, branch and root litter.[16] This process continues, albeit slowly, even when woodland reaches maturity.[18] However, mechanical ground preparation – clearing existing vegetation and improving drainage for tree establishment – disturbs the soil and can cause temporary or permanent SOC loss, depending on previous land use and soil type.[17,43]

Soil in arable fields is typically low in carbon due to regular cultivation for annual crops, so any woodland creation can increase SOC.[44] In contrast, uncultivated pasture and shallow peat soils often have high SOC,[43,45] which can be reduced through inappropriate ground preparation for trees.[44,46] Woodland becomes a net carbon sink once sequestration in woody biomass compensates for this,[17,32,43] and SOC eventually recovers to pre-disturbance levels or above.[46–48] A recent analysis has suggested that tree planting on shallow peat can result in a net carbon source for several decades.[33]

Deeper peat soils in functioning bogs slowly sequester carbon by forming peat from partially decayed vegetation under waterlogged conditions. Historic tree planting schemes drained the bogs, preventing further formation and causing substantial SOC loss. 9% of the UK's deep peats are degraded under forestry.[49] Woodland creation on peat deeper than 50 cm is now prohibited under the UK Forestry Standard.[49,50] Some argue that woodlands should be created on higher value agricultural land to avoid all peat soils.[33,51]

Considerations in woodland creation

Different stakeholders have differing objectives when creating woodland (Box 3), which influence decisions on where woodland should be created, how it should be established, and what tree species should be included. The UK Forestry Standard sets out legal requirements and good practice guidelines for sustainable forest management in the UK, and is used to assess grant and planning applications.[50]

Where to increase tree cover

The possible benefits delivered by woodland are determined by location and can be modelled across landscapes.[8,54,55] The modelling results depend on which benefits are desired, and site choice for woodland creation needs to account for local priorities.[55–57] For example, creating woodland near urban areas maximises recreation opportunities, with substantial social value.[58] Trees are an integral part of urban green infrastructure, delivering a range of benefits (PB-26), but increasing urban tree cover is challenging.[59,60]

Woodland opportunity maps attempt to identify, at a coarse scale, land suitable for trees, avoiding priority habitats for biodiversity, peat soils and the most productive farmland.[51,61–64] They do not indicate land availability or other constraints to woodland creation. Opportunity mapping typically finds that growing trees on low-quality arable land and cultivated grassland has the maximum potential to increase biodiversity

Box 3: Non-carbon reasons for woodland creation

- **Timber**. Timber sales are the chief source of income for woodlands and are important for the rural economy in parts of the UK. It requires expert woodland management and site appropriate species.[65,66]
- **Biodiversity**. Woodland creation on agricultural land of low habitat value is likely to increase biodiversity locally,[65,67–70] and benefit movement of wildlife across landscapes.[71–73] Just increasing woodland cover does not necessarily benefit woodland species; the ability of species present to move between woodlands, the species of tree, and the area, age and the management of woodland are all key.[72,74,75] Woodland creation should also be excluded from existing biodiverse non-woodland habitats.[50,76]
- **Game.** Some land managers create and manage woodland to improve the sporting value of land, particularly for pheasant shooting.[77–80] High pheasant densities can decrease biodiversity locally, but the woodlands and associated habitats have wider biodiversity benefits.[81,82]
- **Flooding.** Uptake and interception of water by trees and increased infiltration of water into woodland soils can mitigate local flooding following heavy rainfall;[83–86] contributing to catchment natural flood management (PN-623). For maximum benefit, the location of new woodlands should be spatially targeted.
- **Water quality and soil erosion.** Broadleaf woodland alongside rivers and streams can stabilise watercourse banks,[87,88] and benefit aquatic biodiversity by reducing water temperature fluctuations.[89–91] Trees can also intercept nutrients and sediment washed off farmland, although grassy strips are generally more effective.[92,93]
- **Air quality.** Tree leaves can absorb the pollutant ammonia from the air,[94] reducing damage to sensitive habitats from deposition on vegetation and soil (PN-458).[95–97] Removal of air pollutants by UK woodland saved £938 million of health costs in 2017.[98]
- **Recreation, health and well-being**. Woodland can provide recreation opportunities, benefiting physical health and mental well-being (PN-538).[99]

and soil carbon, and the least impact on agricultural production. Compared with remote upland sites, these land types are also likely to be readily accessible, both with machinery for tree planting and management, and for public recreation. In addition, siting trees in hedgerows, along rivers and streams, in agroforestry systems, and small copses in gullies, steep banksides and difficult-to-manage field corners can increase tree cover and sequester carbon with little or no loss of farmland productivity.[56,100–105]

How to increase tree cover

Woodland creation is not only achieved by planting trees; trees can be planted outside of woodland (such as in agroforestry systems), and on some sites woodland can establish from naturally available seeds. These methods can differ in cost, reliability of establishment and delivery of benefits.

Plantations

The vast majority of intentional woodland creation in the UK in recent decades has relied on government-funded tree planting,[17] and is the most appropriate option for timber production. Tree species choice and management requirements depend on objectives, but careful planting and management increases the success of tree establishment and growth. Management can include weeding to improve tree growth; replacing dead trees and controlling grey squirrels and deer (PN-303, PN-325). Saplings are typically protected from deer and livestock browsing by fencing, or plastic tubes in the case of small-scale broadleaf planting. Later, thinning out can improve the growth of remaining trees for timber and create open spaces and habitat patches benefiting biodiversity.

Agroforestry

Agroforestry systems integrate agriculture and trees.[106] This includes planting fruit, nut or timber trees in wide-spaced rows across arable or pasture fields, along with shelterbelts (blocks of trees protecting crops and livestock from bad weather), hedges and small farm woodlands.[107] Well-designed agroforestry can positively benefit agricultural productivity and improve farm economic viability while delivering environmental benefits.[108–112] As such, agroforestry practices can increase tree cover across all agricultural land classes without compromising food production and may appeal to more land managers than large-scale woodland creation.[113]

Natural processes

Natural regeneration can lead to the development of new woodland on previously open ground. This natural colonisation or regeneration can contribute to rewilding approaches,[114,115] which generally seek to restore self-regulating natural processes (PN-537). Advantages of relying on natural processes include reduced risk of soil carbon loss (Box 2) and biodiversity benefits from the diverse structure of natural tree growth, and locally adapted seed could increase woodland resilience. Some NGOs argue that natural processes should be the 'default' means of creating woodland,[116] but current grant schemes are not well suited to this.

Success depends on the availability of seed sources such as the proximity of existing woodland. This could result in natural processes taking decades to create woodland or in the dominance of a single early-arriving species like birch. Deer browsing (eating tree vegetation, particularly young stems) also needs to be prevented through costly fencing or shooting to allow trees to establish. Such factors can result in unreliable near-term (decadal) carbon sequestration from woodland creation via natural processes compared with planting trees.[117,118] There is a lack of research in the UK to determine if natural processes can deliver the magnitude or speed of carbon sequestration required to meet net zero targets.[17]

Tree species choice

Apart from Scots pine, all commercial conifer species grown in the UK are non-native and were mostly introduced in recent centuries for timber production (such as Sitka spruce or Corsican pine). Conifers account for 51% of the UK's tree cover and 92% of timber harvested from woodlands in 2019, although the proportions differ between UK countries.[12,53,119] Most common broadleaf species are native (such as oak or beech) or were introduced sufficiently long ago to be considered naturalised (such as sycamore or sweet chestnut) and are more valuable for biodiversity and other benefits (Box 3).[68,69] For instance, 25% of UK species of conservation concern rely on native trees as a habitat or as a food source.[120]

In optimal conditions, commercial conifer species grow and sequester carbon more rapidly than native broadleaves but

have a smaller total carbon stock as mature woodland.[17] The CCC includes both in their woodland creation scenarios,[121] because of the different timescales of sequestration.[122] There are concerns that focusing solely on speed of carbon sequestration may result in monoculture plantations of fast-growing species that deliver few other benefits.[36,56] However, the UK Forestry Standard already requires diverse planting, with a maximum of 75% of one species planted in a woodland.[50]

Resilience to pests and diseases

Many of the UK's tree species are threatened by invasive pests and diseases (PN-394), such as ash dieback.[123] Loss of tree species can have significant financial costs,[124] and reduce carbon storage in woodlands.[8,17] The UK's nursery industry would need to expand to achieve tree planting targets with UK-grown saplings.[8,125] Resilience can be increased by diversifying woodland species composition to include minority native broadleaves like lime and hornbeam, along with non-native species that have previously been trialled in the UK (such as Macedonian pine or Japanese red cedar). Increased tree species diversity has been linked to greater biomass production and soil carbon storage in woodland.[126–128]

Adaptation to climate change

Climate change will affect the suitability of tree species in sites across the UK, both directly through changes in temperature and precipitation, and indirectly through altered frequency and severity of disturbance events such as fire and arrival of pests and diseases.[64,129–131] This will also impact future land suitability for forestry or agriculture.[132,133] Where biodiversity is a key management objective, the UK's native tree species may be sufficiently genetically diverse to be able to adapt to climate change.[134] However, for timber production, if species adaptation does not occur fast enough, assisted migration of climate-adapted seedstock from warmer and drier locations may be necessary, such as French or Spanish seed for southern England.[135] Other adaptation options include enhanced tree breeding and altered woodland management.

Constraints to woodland creation

The rate of woodland creation is increasing, but UK targets are not legally binding and during the past decade have been missed due to economic, land tenure, values (including permanence of land use) and financing challenges.[14,136,137]

Economic viability

A key problem for forestry, if timber is the only source of income, is the several decades required to achieve a return on investment from establishment and management costs.[138,139] Depending on the price of timber, woodland creation is often uneconomic.[113] Government grants and/or private payments for carbon sequestration and other ecosystem services are widely perceived as necessary to incentivise woodland creation by mitigating, at least in part, the early costs of management.

Woodland creation also has an opportunity cost associated with the income foregone from other possible uses of that land. Land is often more valuable if used for agriculture or development.[138,140,141] This is a constraint in lowland areas near towns and cities, particularly in southern England. This is reflected in land prices and is one reason why most large-scale woodland creation occurs in the uplands and Scotland where land is cheaper.[142,143] Land prices and the economic viability of some farms is in part underpinned by the structure of current agricultural subsidies,[139,144] which are due to change in England from 2024 with the introduction of the Environmental Land Management scheme.[23] However, moving from annual agricultural revenue streams to long-term woodland-based income is challenging.[145] The CCC has called for a review of the tax treatment of woodland to ensure there is no tax disadvantage of land use change from agriculture to forestry.[146]

Land tenure

30–40% of UK farms are tenanted, with an average tenancy duration of 3.7 years.[121] Landlord permission is often required for, or tenancy agreement clauses may prevent, tree planting.[138] Tenant farmers are also disincentivised from creating woodland as they are unlikely to see any return on their investment.[79,139] The party that owns carbon sequestered on tenanted farmland in a landlord-tenant relationship (and therefore is able to sell the credits generated) is unclear.[147]

Land manager values, skills and expertise

Farming and forestry are widely viewed as mutually exclusive land uses.[79,113,139] Resistance to tree planting can arise from farmland being seen as 'too good' for woodland, a cultural desire to continue producing food, the permanence of forestry limiting future land use options, and lack of awareness of the benefits of woodland creation.[79,80,138,145,148–151] Many farmers lack the skills, expertise and machinery to establish and manage woodland,[138,139] suggesting a need for advice and information to upskill farmers.[79] Existing woodland owners also identify a lack of skilled forestry contractors as a barrier to expanding their woodlands.[138,140,141]

Financing woodland creation

Challenges with current government grants for woodland creation include insufficient payment rates, complexity of applications, prescriptive planting requirements and changeability of schemes.[79,80,138,140,141,152] For example, grants in England are only available for woodland creation greater than 3 ha,[20,26,31] whereas Scotland and Wales support plantings above 0.25 ha,[29,153] or 0.2 ha in Northern Ireland.[31] In addition to restrictions on tree density and species composition, this makes small-scale woodland creation financially unviable and limits integration of trees into farming landscapes.

The UK Government intends to involve private finance in woodland creation.[21] 'Blended finance' refers to mixed public- and private-sector funding,[154] which could include private payments for ecosystem services such as carbon sequestration, improved water quality or reduced flooding.[21,155] Separate payments for multiple benefits can be stacked to finance otherwise unviable creation projects,[156] as pioneered by the Landscape Enterprise Networks (LENs) approach in Cumbria.[154,157] Voluntary private payments for carbon offsets verified through the Woodland Carbon Code are already part-funding UK projects, with a government-guaranteed price available through the Woodland Carbon Guarantee.[157–159] Examples of small-scale local markets exist for non-carbon ecosystem services, such as improved water quality and reduced flooding (PN-627), via platforms including NatureBid, EnTrade and LENs.[160–162]

POST is an office of both Houses of Parliament, charged with providing independent and balanced analysis of policy issues that have a basis in science and technology. POST is grateful to Matt Jordon for researching this briefing, to the BBSRC for funding his parliamentary fellowship, and to all contributors and reviewers. For further information on this subject, please contact the co-author, Dr Jonathan Wentworth.

Endnotes

1. BEIS (2019). UK becomes first major economy to pass net zero emissions law. *GOV.UK*.
2. Committee on Climate Change (2019). Net Zero: The UK's contribution to stopping global warming. Committee on Climate Change.
3. Climate Change Committee (2020). The Sixth Carbon Budget - The UK's path to Net Zero.
4. Broadmeadow, M. *et al.* (2003). Forests, Carbon and Climate Change: the UK Contribution. 12. Forest Research.
5. Royal Society (Great Britain) *et al.* (2018). Greenhouse gas removal.
6. Lewis, S. L. *et al.* (2019). Comment on "The global tree restoration potential". *Science*, Vol 366, eaaz0388.
7. Friedlingstein, P. *et al.* (2019). Comment on "The global tree restoration potential". *Science*, Vol 366, eaay8060.
8. Natural Capital Committee (2020). Advice on using nature based interventions to reach net zero greenhouse gas emissions by 2050.
9. Griscom, B. W. *et al.* (2017). Natural climate solutions. *Proc. Natl. Acad. Sci.*, Vol 114, 11645–11650.
10. (2009). Combating climate change – a role for UK forests. An assessment of the potential of the UK's trees and woodlands to mitigate and adapt to climate change. The synthesis report. Stationery Office.
11. Hayhow, D. B. *et al.* (2019). The State of Nature 2019. The State of Nature partnership.
12. Forest Research (2020). Forestry Statistics 2020. A compendium of statistics about woodland, forestry and primary wood processing in the United Kingdom.
13. FAO (2020). Global Forest Resources Assessment 2020. FAO.
14. Defra (2020). Tree planting on the up in England - Defra in the media.
15. Johnson, B. (2020). Boris Johnson: Now is the time to plan our green recovery.
16. Morison, J. I. L. *et al.* (2012). Understanding the carbon and greenhouse gas balance of forests in Britain. Forestry Commission.
17. Matthews, R. (2020). ERAMMP Report-36 Annex-4: Climate Change Mitigation. in *Environment and Rural Affairs Monitoring & Modelling Programme (ERAMMP). National Forest in Wales Evidence Review*. Welsh Government.
18. Pan, Y. *et al.* (2011). A Large and Persistent Carbon Sink in the World's Forests. *Science*, Vol 333, 988–993.
19. Hong, S. *et al.* (2020). Divergent responses of soil organic carbon to afforestation. *Nat. Sustain.*, Vol 3, 694–700.
20. Rural Payments Agency (2020). Woodland Creation grant: Countryside Stewardship (from 15 July 2020). 88.
21. Defra (2018). A Green Future: Our 25 Year Plan to Improve the Environment.
22. HM Treasury (2020). Budget 2020: Delivering on our promises to the British people.
23. Defra (2020). The Path to Sustainable Farming: An Agricultural Transition Plan 2021 to 2024. 66.
24. Defra (2020). Nature Recovery Network. *GOV.UK*.
25. Scottish Government (2020). Protecting Scotland, Renewing Scotland.
26. Scottish Forestry (2019). The Forestry Grant Scheme. A guide to grant options for woodland creation. Scottish Government.
27. Mackinnon, J. (2016). Analysis of Current Arrangements for the Consideration and Approval of Forestry Planting Proposals. 28. Scottish Government.
28. Welsh Government (2018). Woodlands for Wales. The Welsh Government's Strategy for Woodlands and Trees.
29. Welsh Government (2020). Glastir Woodland Creation Rules Booklet Version 9. Welsh Government Rural Communities - Rural Development Programme for Wales 2014 - 2020.
30. DAERA (2020). Poots' planting pledge. *Department of Agriculture, Environment and Rural Affairs*.
31. DAERA (2020). DAERA forestry grants. *Department of Agriculture, Environment and Rural Affairs*.
32. Mayer, M. *et al.* (2020). Tamm Review: Influence of forest management activities on soil organic carbon stocks: A knowledge synthesis. *For. Ecol. Manag.*, Vol 466, 118127.
33. Matthews, K. B. *et al.* (2020). Not seeing the carbon for the trees? Why area-based targets for establishing new woodlands can limit or underplay their climate change mitigation benefits. *Land Use Policy*, Vol 97, 104690.
34. Stephenson, N. L. *et al.* (2014). Rate of tree carbon accumulation increases continuously with tree size. *Nature*, Vol 507, 90–93.
35. Luyssaert, S. *et al.* (2008). Old-growth forests as global carbon sinks. *Nature*, Vol 455, 213–215.
36. Seddon, N. *et al.* (2019). Grounding nature-based climate solutions in sound biodiversity science. *Nat. Clim. Change*, Vol 9, 84–87.
37. Crane, E. (2020). Woodlands for climate and nature: A review of woodland planting and management approaches in the UK for climate change mitigation and biodiversity conservation. Report to the RSPB.
38. Beyer, G. *et al.* (2011). Tackle Climate Change: Use Wood. 84.
39. Amiri, A. *et al.* (2020). Cities as carbon sinks—classification of wooden buildings. *Environ. Res. Lett.*, Vol 15, 094076.
40. Harmon, M. E. (2019). Have product substitution carbon benefits been overestimated? A sensitivity analysis of key assumptions. *Environ. Res. Lett.*, Vol 14, 065008.
41. Sathre, R. *et al.* (2010). Meta-analysis of greenhouse gas displacement factors of wood product substitution. *Environ. Sci. Policy*, Vol 13, 104–114.
42. Waugh, A. *et al.* (2018). 100 Projects UK CLT. 324. Waugh Thistleton Architects.
43. Vanguelova, E. *et al.* (2018). Afforestation and restocking on peaty soils – new evidence assessment. 43. ClimateXChange.
44. Guo, L. B. *et al.* (2002). Soil carbon stocks and land use change: a meta analysis. *Glob. Change Biol.*, Vol 8, 345–360.
45. Ostle, N. J. *et al.* (2009). UK land use and soil carbon sequestration. *Land Use Policy*, Vol 26, S274–S283.
46. Vanguelova, E. I. *et al.* (2019). Impact of Sitka spruce (Picea sitchensis (Bong.) Carr.) afforestation on the carbon stocks of peaty gley soils – a chronosequence study in the north of England. *For. Int. J. For. Res.*, Vol 92, 242–252.
47. Dawson, J. J. C. *et al.* (2007). Carbon losses from soil and its consequences for land-use management. *Sci. Total Environ.*, Vol 382, 165–190.
48. Zerva, A. *et al.* (2005). Soil carbon dynamics in a Sitka spruce (Picea sitchensis (Bong.) Carr.) chronosequence on a peaty gley. *For. Ecol. Manag.*, Vol 205, 227–240.
49. Sloan, T. J. *et al.* (2018). Peatland afforestation in the UK and consequences for carbon storage. *Mires Peat*, 1–17.
50. Forestry Commission (2017). The UK Forestry Standard. *GOV.UK*.
51. Sing, L. *et al.* (2020). Analysis of Land Suitability for Woodland Expansion in Scotland: update 2020. ClimateXChange.
52. Law, B. E. *et al.* (2011). Forest sector carbon management, measurement and verification, and discussion of policy related to climate change. *Carbon Manag.*, Vol 2, 73–84.
53. John Clegg & Co *et al.* (2019). The UK Forest Market Report. Issue 21.
54. Bailey, N. *et al.* (2006). Maximising the natural capital benefits of habitat creation: Spatially targeting native woodland using GIS. *Landsc. Urban Plan.*, Vol 75, 227–243.
55. Verhagen, W. *et al.* (2016). Effects of landscape configuration on mapping ecosystem service capacity: a review

of evidence and a case study in Scotland. *Landsc. Ecol.*, Vol 31, 1457–1479.
56. Woodland Trust (2020). Emergency Tree Plan for the UK. How to increase tree cover and address the nature and climate emergency.
57. Broadmeadow, S. *et al.* (2014). Opportunity mapping for woodland creation to reduce diffuse water pollution and flood risk in England and Wales. Forest Research.
58. Bateman, I. J. *et al.* (2013). Bringing Ecosystem Services into Economic Decision-Making: Land Use in the United Kingdom. *Science*, Vol 341, 45–50.
59. Doick, K. J. *et al.* (2020). Historic Urban Tree Canopy Cover of Great Britain. *Forests*, Vol 11, 1049.
60. Forestry Commission (2019). Urban Tree Challenge Fund. *GOV.UK*.
61. Terra Sulis Research (2020). Opportunity Woodland Mapping in England. Report to Friends of the Earth.
62. Welsh Government Glastir Woodland Creation - Opportunities Map.
63. Sing, L. *et al.* (2013). Woodland expansion in Scotland: an assessment of the opportunities and constraints using GIS. *Scott. For.*, Vol 67, 9.
64. Bell, G. *et al.* (2020). Tree Suitability Modelling – Planting Opportunities for Sessile Oak and Sitka Spruce in Wales in a Changing Climate. Environment Systems Ltd.
65. Confor (2020). Biodiversity, forestry and wood. An analysis of the biodiversity benefits of modern forestry and wood production.
66. Greig, S. (2015). A Long Term Carbon Account for Forestry at Eskdalemuir. Confor.
67. Quine, C. P. *et al.* (2010). Plantations of exotic tree species in Britain: irrelevant for biodiversity or novel habitat for native species? *Biodivers. Conserv.*, Vol 19, 1503–1512.
68. Stephens, S. S. *et al.* (2007). Forest Plantations and Biodiversity: A Fresh Perspective. *J. For.*, 7.
69. Bremer, L. L. *et al.* (2010). Does plantation forestry restore biodiversity or create green deserts? A synthesis of the effects of land-use transitions on plant species richness. *Biodivers. Conserv.*, Vol 19, 3893–3915.
70. Burton, V. *et al.* (2018). Reviewing the evidence base for the effects of woodland expansion on biodiversity and ecosystem services in the United Kingdom. *For. Ecol. Manag.*, Vol 430, 366–379.
71. Hodgson, J. A. *et al.* (2011). Habitat re-creation strategies for promoting adaptation of species to climate change. *Conserv. Lett.*, Vol 4, 289–297.
72. Whytock, R. C. *et al.* (2018). Bird-community responses to habitat creation in a long-term, large-scale natural experiment. *Conserv. Biol.*, Vol 32, 345–354.
73. Feber, R. (2017). The role of trees outside woods (TOWs) in contributing to the ecological connectivity and functioning of landscapes. Woodland Trust.
74. Irmler, U. *et al.* (2010). Species richness of saproxylic beetles in woodlands is affected by dispersion ability of species, age and stand size. *J. Insect Conserv.*, Vol 14, 227–235.
75. Lawton, J. (2010). Making Space for Nature: A review of England's Wildlife Sites and Ecological Network. Report to Defra. 119.
76. Veldman, J. W. *et al.* (2019). Comment on "The global tree restoration potential". *Science*, Vol 366, eaay7976.
77. PACEC (2014). The Value of Shooting. The economic, environmental and social contribution of shooting sports to the UK.
78. Oldfield, T. E. E. *et al.* (2003). Field sports and conservation in the United Kingdom. *Nature*, Vol 423, 531–533. Nature Publishing Group.
79. Lawrence, A. *et al.* (2014). Private landowners' approaches to planting and managing forests in the UK: What's the evidence? *Land Use Policy*, Vol 36, 351–360.
80. Lawrence, A. *et al.* (2010). Landowners' attitudes to woodland creation and management in the UK. 66. Forest Research.
81. Sage, R. B. *et al.* (2020). Summary review and synthesis: effects on habitats and wildlife of the release and management of pheasants and red-legged partridges on UK lowland shoots. *Wildl. Biol.*, Vol 2020,
82. Mason, L. R. *et al.* (2020). The impacts of non-native gamebird release in the UK: an updated evidence review. RSPB Research Report No. 66. 170. RSPB Centre for Conservation Science, Sandy, UK.
83. Marshall, M. R. *et al.* (2014). The impact of rural land management changes on soil hydraulic properties and runoff processes: results from experimental plots in upland UK: IMPACT OF LAND MANAGEMENT CHANGE ON RUNOFF PROCESSES. *Hydrol. Process.*, Vol 28, 2617–2629.
84. Rotherham, I. D. (2015). Issues of water and flooding for trees, woods and forests. *Arboric. J.*, Vol 37, 200–223.
85. Filoso, S. *et al.* (2017). Impacts of forest restoration on water yield: A systematic review. *PLOS ONE*, Vol 12, e0183210.
86. Confor (2016). Forestry and Flooding.
87. McIvor, I. R. *et al.* (2007). Structural root growth of young Veronese poplars on erodible slopes in the southern North Island, New Zealand. *Agrofor. Syst.*, Vol 72, 75–86.
88. Hubble, T. C. T. *et al.* (2010). The role of riparian trees in maintaining riverbank stability: A review of Australian experience and practice. *Ecol. Eng.*, Vol 36, 292–304.
89. Johnson, M. F. *et al.* (2015). Seeing the landscape for the trees: Metrics to guide riparian shade management in river catchments. *Water Resour. Res.*, Vol 51, 3754–3769.
90. Garner, G. *et al.* (2015). Inter-annual variability in the effects of riparian woodland on micro-climate, energy exchanges and water temperature of an upland Scottish stream. *Hydrol. Process.*, Vol 29, 1080–1095.
91. Hannah, D. M. *et al.* (2015). River water temperature in the United Kingdom: Changes over the 20th century and possible changes over the 21st century. *Prog. Phys. Geogr. Earth Environ.*, Vol 39, 68–92. SAGE Publications Ltd.
92. Udawatta, R. P. *et al.* (2010). Agroforestry and grass buffer effects on water quality in grazed pastures. *Agrofor. Syst.*, Vol 79, 81–87.
93. Cole, L. J. *et al.* (2020). Managing riparian buffer strips to optimise ecosystem services: A review. *Agric. Ecosyst. Environ.*, Vol 296, 106891.
94. Patterson, P. H. *et al.* (2008). The Potential for Plants to Trap Emissions from Farms with Laying Hens. 1. Ammonia. *J. Appl. Poult. Res.*, Vol 17, 54–63.
95. Dragosits, U. *et al.* (2006). The potential for spatial planning at the landscape level to mitigate the effects of atmospheric ammonia deposition. *Environ. Sci. Policy*, Vol 9, 626–638.
96. Bealey, W. J. *et al.* (2014). Modelling agro-forestry scenarios for ammonia abatement in the landscape. *Environ. Res. Lett.*, Vol 9, 125001.
97. Rowe, E. *et al.* (2019). Trends Report 2019: Trends in critical load and critical level exceedances in the UK. Report to Defra under Contract AQ0843, CEH Project NEC05708. 80.
98. Office for National Statistics (2020). Woodland natural capital accounts, UK - Office for National Statistics.
99. Doimo, I. *et al.* (2020). Forest and Wellbeing: Bridging Medical and Forest Research for Effective Forest-Based Initiatives. *Forests*, Vol 11, 791. Multidisciplinary Digital Publishing Institute.
100. NFU (2019). Achieveing Net Zero. Farming's 2040 goal. National Farmers' Union.
101. Morley, K. *et al.* (2012). Clough Woodland. Planting new woodland. Moors for the Future Partnership.

102. Axe, M. S. *et al.* (2017). Carbon storage in hedge biomass—A case study of actively managed hedges in England. *Agric. Ecosyst. Environ.*, Vol 250, 81–88.
103. Beckert, M. R. *et al.* (2016). Soil and tree biomass carbon sequestration potential of silvopastoral and woodland-pasture systems in North East Scotland. *Agrofor. Syst.*, Vol 90, 371–383.
104. Upson, M. A. *et al.* (2016). Soil carbon changes after establishing woodland and agroforestry trees in a grazed pasture. *Geoderma*, Vol 283, 10–20.
105. Fornara, D. A. *et al.* (2018). Land use change and soil carbon pools: evidence from a long-term silvopastoral experiment. *Agrofor. Syst.*, Vol 92, 1035–1046.
106. (2018). Temperate Agroforestry Systems. CABI.
107. (2019). The Agroforestry Handbook - Agroforestry for the UK. Soil Association.
108. Kay, S. *et al.* (2019). Agroforestry is paying off – Economic evaluation of ecosystem services in European landscapes with and without agroforestry systems. *Ecosyst. Serv.*, Vol 36, 100896.
109. Torralba, M. *et al.* (2016). Do European agroforestry systems enhance biodiversity and ecosystem services? A meta-analysis. *Agric. Ecosyst. Environ.*, Vol 230, 150–161.
110. Pent, G. J. (2020). Over-yielding in temperate silvopastures: a meta-analysis. *Agrofor. Syst.*, Vol 94, 1741–1758.
111. Jordon, M. W. *et al.* (2020). Implications of Temperate Agroforestry on Sheep and Cattle Productivity, Environmental Impacts and Enterprise Economics. A Systematic Evidence Map. *Forests*, Vol 11, 1321.
112. Varah, A. *et al.* (2014). Delivering food production, biodiversity and other ecosystem services in UK agriculture: can agroforestry do it all? *Agric. Environ. X*, Vol Delivering Multiple Benefits from our Land: Sustainable Development in Practice, 99–105.
113. Hardaker, A. (2018). Is forestry really more profitable than upland farming? A historic and present day farm level economic comparison of upland sheep farming and forestry in the UK. *Land Use Policy*, Vol 71, 98–120.
114. Dandy, N. *et al.* (2019). Rewilding forestry. *For. Policy Econ.*, Vol 109, 101996.
115. Sandom, C. J. *et al.* (2019). Rewilding in the English uplands: Policy and practice. *J. Appl. Ecol.*, Vol 56, 266–273.
116. Rewilding Britain (2020). Reforesting Britain: Why natural regeneration should be our default approach to woodland expansion.
117. Lamb, A. *et al.* (2016). The potential for land sparing to offset greenhouse gas emissions from agriculture. *Nat. Clim. Change*, Vol 6, 488–492.
118. Harmer, R. *et al.* (2001). Vegetation changes during 100 years of development of two secondary woodlands on abandoned arable land. *Biol. Conserv.*, Vol 101, 291–304.
119. John Clegg Consulting Ltd (2016). Wood Fibre Availability & Demand in Britain 2013-2035. Prepared for Confederation of Forest Industries (Confor), Forestry Commission, UK Forest Products Association (UKFPA) & Wood Panel Industries Federation (WPIF).
120. Webb, J. R. *et al.* (2010). Managing for species: Integrating the needs of England's priority species into habitat management.
121. Committee on Climate Change (2018). Land use: Reducing emissions and preparing for climate change. *Committee on Climate Change*.
122. Dewar, R. C. *et al.* (1992). Carbon sequestration in the trees, products and soils of forest plantations: an analysis using UK examples. *Tree Physiol.*, Vol 11, 49–71.
123. Broome, A. *et al.* (2019). Responding to ash dieback (Hymenoscyphus fraxineus) in the UK: woodland composition and replacement tree species. *For. Int. J. For. Res.*, Vol 92, 108–119.
124. Hill, L. *et al.* (2019). The £15 billion cost of ash dieback in Britain. *Curr. Biol.*, Vol 29, R315–R316.
125. Confor (2019). Woodland carbon targets for the UK.
126. Gamfeldt, L. *et al.* (2013). Higher levels of multiple ecosystem services are found in forests with more tree species. *Nat. Commun.*, Vol 4, 1340. Nature Publishing Group.
127. Tilman, D. *et al.* (2014). Biodiversity and Ecosystem Functioning. *Annu. Rev. Ecol. Evol. Syst.*, Vol 45, 471–493.
128. Martin-Guay, M.-O. *et al.* (2019). Implications of contrasted above- and below-ground biomass responses in a diversity experiment with trees. *J. Ecol.*, Vol 108, 405–414.
129. (2016). Agriculture and Forestry Climate Change Impacts Summary Report, Living With Environmental Change.
130. Ray, D. *et al.* (2010). Climate change: impacts and adaptation in England's woodlands. Forestry Commission England.
131. Kirby, K. J. *et al.* (2009). The adaptation of UK forests and woodlands to climate change. in *Combating Climate Change - a role for UK forests. An assessment of the potential of the UK's trees and woodlands to mitigate and adapt to climate change*. The Stationery Office, Edinburgh.
132. Gimona, A. *et al.* (2012). Woodland networks in a changing climate: Threats from land use change. *Biol. Conserv.*, Vol 149, 93–102.
133. Ritchie, P. D. L. *et al.* (2019). Large changes in Great Britain's vegetation and agricultural land-use predicted under unmitigated climate change. *Environ. Res. Lett.*, Vol 14, 114012.
134. Natural England *et al.* (2020). Climate Change Adaptation Manual - Evidence to support nature conservation in a changing climate, 2nd Edition. Natural England.
135. Whittet, R. *et al.* (2019). Genetic considerations for provenance choice of native trees under climate change in England. Forestry Commission Research Report. Forestry Commission.
136. Marsh, S. (2020). Disappointing planting figures in England still far below Government target. *Woodland Trust*.
137. BBC News (2020). Climate change: Wales lags behind on planting new trees.
138. Eves, C. *et al.* (2014). Analysis of the potential effects of various influences and interventions on woodland management and creation decisions, using a segmentation model to categorise sub-groups - Volume 1: Summary for Policy-Makers. Defra.
139. McAleenan, B. (2019). Bigger, Better Forests. Policy Exchange.
140. Royal Forestry Society (2020). Woodland Creation Opportunities and Barriers - survey results 2020.
141. Hemery, G. *et al.* (2020). Awareness, action and aspirations in the forestry sector in responding to environmental change: Report of the British Woodlands Survey 2020. 33.
142. Savills (2019). The Farmland Market.
143. Savills *et al.* (2019). The Forestry Market.
144. O'Neill, C. *et al.* (2020). Forest regeneration on European sheep pasture is an economically viable climate change mitigation strategy. *Environ. Res. Lett.*,
145. Wynne-Jones, S. (2013). Carbon blinkers and policy blindness: The difficulties of 'Growing Our Woodland in Wales'. *Land Use Policy*, Vol 32, 250–260.
146. Committee on Climate Change (2020). Land use: Policies for a Net Zero UK.
147. National Trust Personal Communication.
148. Allison, L. (1996). On Planning a Forest: Theoretical Issues and Practical Problems. *Town Plan. Rev.*, Vol 67, 131–143. Liverpool University Press.
149. Watkins, C. *et al.* (1996). Constraints on farm woodland planting in England: a study of Nottinghamshire farmers. *Forestry*, Vol 69, 167–176.
150. Burton, R. J. F. (2004). Seeing Through the 'Good Farmer's' Eyes: Towards Developing an Understanding of the

Social Symbolic Value of 'Productivist' Behaviour. *Sociol. Rural.*, Vol 44, 195–215.
151. Church, A. *et al.* (2008). Landowner responses to financial incentive schemes for recreational access to woodlands in South East England. *Land Use Policy*, Vol 25, 1–16.
152. Urquhart, J. *et al.* (2010). Private Ownership and Public Good Provision in English Woodlands. *Small-Scale For.*, Vol 9, 1–20.
153. Scottish Government (2016). Woodland Creation – Small or Farm Woodland.
154. BEIS (2019). Green Finance Strategy. Transforming Finance for a Greener Future. HM Government.
155. Dittrich, R. *et al.* (2019). A cost-benefit analysis of afforestation as a climate change adaptation measure to reduce flood risk. *J. Flood Risk Manag.*, Vol 12,
156. Elliott, J. *et al.* (2019). New routes to decarbonise land use with Natural Infrastructure Schemes. Green Alliance.
157. 3keel *et al.* (2020). Integrating Natural Capital Schemes. Opportunity analysis for integrating carbon markets into multifunctional landscape marketplaces, such as those developed by the Landscape Enterprise Networks (LENs) approach.
158. Allen, M. *et al.* (2020). The Oxford Principles for Net Zero Aligned Carbon Offsetting. 15. University of Oxford.
159. Forestry Commission (2019). Woodland Carbon Guarantee. *GOV.UK*.
160. Curtis, T. Landscape innovation. *3Keel*.
161. Environment Agency *et al.* NatureBid.
162. EnTrade EnTrade.