Imperial College London

Grantham Institute
Discussion paper 6

July 2020

What role can forests play in tackling climate change?

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Headlines

- Trees and forest ecosystems help limit global warming by reducing the concentration of carbon dioxide in the atmosphere, alongside simultaneous 'co-benefits' for biodiversity, local economies, human health and leisure.
- Wherever possible, existing native ecosystems such as savannas, grasslands and forests should be protected, and damaged or destroyed ecosystems should be restored.
- Mixed-tree plantations and managed native forests can help remove carbon dioxide from the atmosphere if they are correctly located, planned and implemented.
- Plantations also can reduce pressure on native forests, yield wood products that replace fossil fuels, and provide socio-economic benefits.
- Sensitivity to both environmental and economic contexts is essential to realising the greatest climate benefits and co-benefits of tree planting.
- Ultimately, tree planting is not a silver bullet to averting climate change. Only rapid reduction of greenhouse gas emissions can halt the ongoing rise in global temperatures.

Introduction

Rapidly and significantly reducing the emission of greenhouse gases into the atmosphere is essential to limit global warming. To achieve this, the Intergovernmental Panel on Climate Change (IPCC) indicates a diverse portfolio of strategies to lower, and ultimately halt, the emission of carbon dioxide (CO_2 – a greenhouse gas that leads to global warming) alongside measures to reduce its concentration in the atmosphere.

'Net-zero' describes the situation where the amount of carbon dioxide emitted by all human activities – such as transport, industry, agriculture and heating our homes – is balanced by activities that remove or 'capture' carbon dioxide from the atmosphere[1]. Scientists in the United Kingdom government's independent advisory group, the Committee on Climate Change, called for the UK to have a 'net-zero' economy by 2050, in order to meet the commitments of the 2015 Paris Climate Agreement.

Contents

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The UK government enshrined this target in law in 2019. Other nations, states, regions, businesses and organisations have set their own targets.

Tree planting has been suggested as a way of capturing carbon dioxide because trees absorb carbon dioxide through photosynthesis, releasing oxygen back into the atmosphere and withholding the carbon. Some of this carbon becomes part of, or 'is stored in', wood, leaves, roots and soil. This paper consolidates knowledge on the potential environmental, economic and societal benefits of using trees to reduce the concentration of carbon dioxide in the atmosphere. It highlights areas for further research and defines the limits of trees' ability to halt the progress of climate change.

How much can trees help to combat global warming?

Animals, fungi, bacteria and other organisms feed on the living and dead matter (biomass) of plants, soils and sediments – and together these organisms make up an ecosystem. Some carbon naturally returns to the atmosphere when organisms produce carbon dioxide by breathing and methane (another potent greenhouse gas) by digestion, otherwise most of the carbon is effectively stored within an intact ecosystem (see Figure 1).

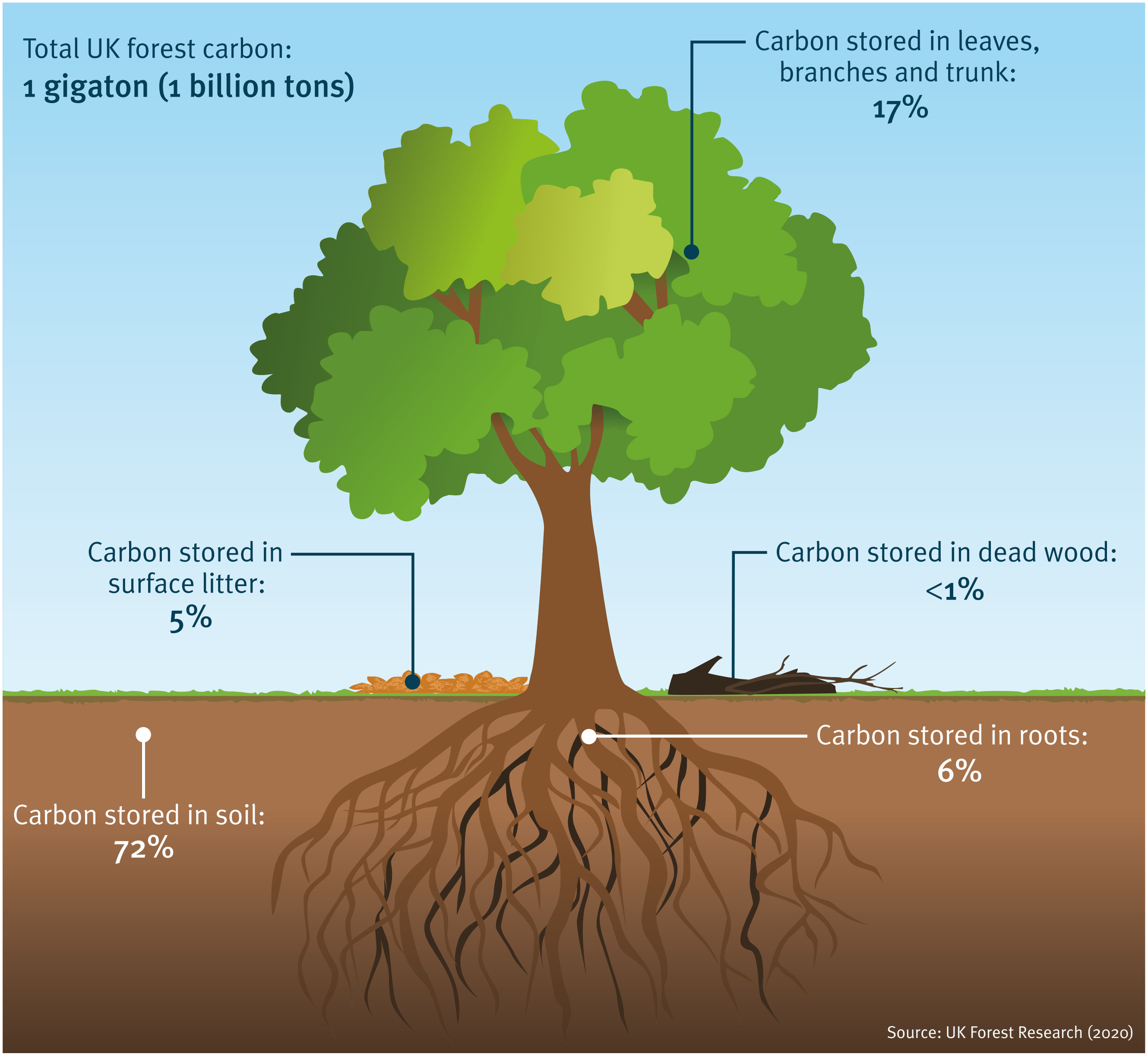

Figure 1: Areas where carbon is stored in a typical temperate forest in the United Kingdom; derived from UK Forest Research: https://www.forestresearch.gov.uk/tools-and-resources/statistics/forestry-statistics/forestry-statistics-2018/uk-forests-and-climate-change/forest-carbon-stock/

Forest ecosystems account for around 45% of all the carbon stored on land[2]. Re-growing and expanding existing forests (reforestation), and growing new forests (afforestation), have been proposed as ways to capture and store additional carbon dioxide from the atmosphere. Realistic estimates suggest that tree planting on a world-wide scale could capture a maximum of 40–100 gigatons (a gigaton is a billion tons) of carbon from the atmosphere by the time these forests reach maturity[3]. This is equivalent to about one decade's worth of emissions at current rates, or 6–16% of total emissions from human activities since the Industrial Revolution began (which is around 600 gigatons)[4].

Put another way, reforestation and afforestation could reduce the concentration of carbon dioxide in the atmosphere by approximately 15–30 parts per million (ppm)[5]. To place this into context, the concentration has risen at an unprecedented rate from about 280ppm before the Industrial Revolution began, to the present-day concentration of 400ppm and above.

Therefore, even based on optimistic estimates, tree-planting alone will be insufficient to bring carbon dioxide concentration to net-zero, unless immediate and sustained action is also taken to reduce the current rate of emission[1,6].

Importantly, however, in addition to capturing carbon dioxide, preserving and expanding forests can also deliver a wide range of social, economic and environmental 'co-benefits'.

How to maximise the amount of carbon dioxide captured by trees

The effectiveness of tree planting in capturing carbon dioxide from the atmosphere is controlled by three main factors.

Location of trees

Forested and formerly forested tropical ecosystems, such as the Amazon Rainforest, provide the greatest potential for both large-scale reforestation and afforestation (see Figure 2 for an illustration of the global range of different landscapes). These regions support forests capable of rapid growth and have a high potential to capture carbon dioxide from the atmosphere[7,8].

In comparison, native forests at high latitudes in the northern hemisphere, such as the boreal forests in North America, Russia and Scandinavia store large amounts of carbon in their soils but, they take longer to grow than trees at lower latitudes, meaning they take longer to accumulate carbon.

Planting trees in some high-latitude ecosystems can conversely contribute to global warming. E.g. in landscapes where snow lies for most of the year, native short-statured vegetation is often covered by a white and reflective layer, but tall trees grow above the snow and are a darker colour, thus absorbing more of the sun's heat[9].

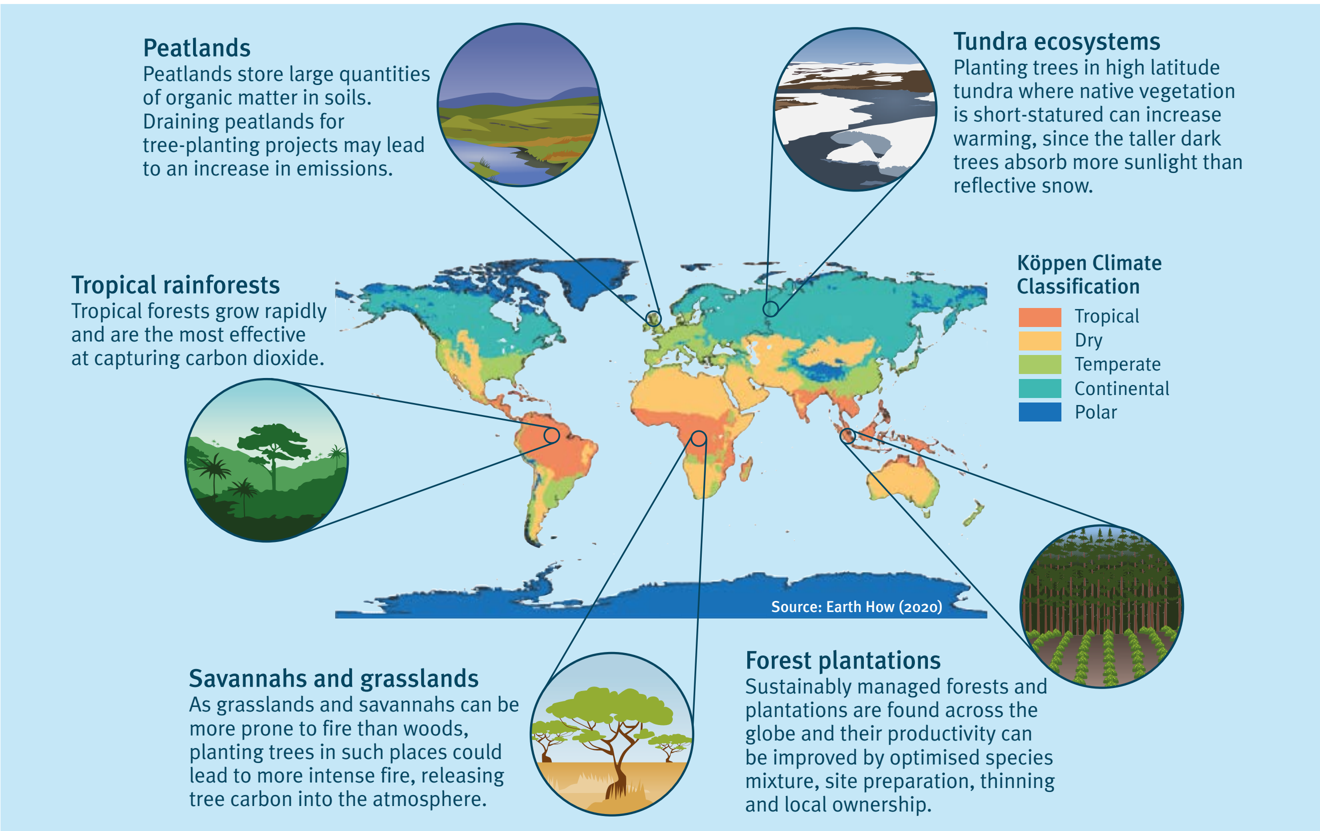

Figure 2: Implications of large-scale tree planting in various climatic zones and ecosystems. The Köppen climate classification divides climates into five main groups, based on seasonal precipitation and temperature patterns.
Source: https://earthhow.com/koppen-climate-classification/

Afforestation in places where forests would not naturally grow can also lead to carbon dioxide being released into the atmosphere instead of removed. For example, peatland contains large amounts of carbon trapped within the slowly decomposing soil. Draining peatland for tree-planting would release the carbon that is stored there[10]. Afforesting savannas and grasslands could both increase the risk of intense fires – potentially leading to the release of huge amounts of stored carbon dioxide – and may also harm the biodiversity including iconic endangered species[4].

Choice and management of tree species

Planting a diversity of native tree species is more effective in storing carbon and comes with a range of social, economic and environmental co-benefits (see examples in Figure 3). The best strategies ensure trees have a higher chance of survival and a faster rate of growth, leading to more carbon dioxide being captured from the atmosphere by the ecosystem as a whole[11,12,13,14].

Diverse forests can support a wide range of other plants and animals and improve the landscape's resilience to disturbance by other human activities. A good example is the enhanced bird diversity supported by plantations established as part of China's 'Grain-for-Green' programme[15]. Also, according to the UK's Woodland Trust, plantations involving native trees also offer a natural means to protect against hazards such as the risk of flooding by storing water in uplands.

By contrast, single-species (or 'monoculture') plantations are often dominated by fast-growing pine, eucalyptus and poplar, and are usually not native to the location where they are planted. This leads to them being limited in the amount of additional carbon they store over the long term[16,17].

What happens to the carbon after it becomes a tree?

Carbon is stored within plant biomass on timescales of seasons to decades. When a tree dies or is harvested, that carbon can be stored in wooden products, or in soils and sediments for much longer periods, and this helps to limit global warming.

For example, the amount of carbon stored in soils is larger than the amount in plants and the atmosphere combined. Soil carbon changes very slowly, and some is very stable; potentially persisting for millennia[18]. Effective forest management can ensure that some of the carbon is transferred to stable soil stores. For example, carefully planned fertilisation with nutrients both optimises the trees' productivity and can also help stabilise soil biomass in some regions[19]. Controlled burning of land can lead to formation of carbon- and nutrient-rich soils e.g. Terra preta, the very dark and fertile soil developed by human activities in the Amazon[20,21]). The factors that control the formation and decomposition of soil carbon are dependent on the location of the forest. For example, as mentioned above, planting trees in some ecosystems such as peatland can instead lead to carbon emissions[22,23,24]. Ultimately, site-specific soil properties determine how effectively animals and other organisms can break down plant biomass into soil matter, thus storing carbon for the long term[25,26,27].

Managing forests to harvest wood and create new products is another way to ensure carbon is continuously captured and stored (see examples in Figure 3). For most ecosystems, their 'carbon carrying capacity' is finite and converting tree carbon into long-lived wood products can help optimise long-term carbon storage[28,29,30]. Harvested wood products can also be substituted for some fossil-fuel intensive products, such as the steel and cement used heavily in the construction sector[31,32], or burned to produce 'bioenergy' from waste matter or residues that would otherwise emit carbon when decomposing. Harvested wood products, commercialised under good management, can deliver enhanced economic security for local communities. Wood can be removed through targeted thinning and/or selective harvesting, but must ensure that the forest ecosystem is not compromised.

Key policy decisions for climate-smart tree planting

Forestry-related policies must balance multiple objectives: maximising carbon dioxide captured from the atmosphere and storing it over the long term; protecting biodiversity; assisting protection against natural hazards (e.g. floods and landslides); and enhancing local economies. To achieve these goals, policymakers should:

- Diversify land-use to balance environmental and economic objectives;
- Emphasise reforestation and the protection of existing forests; and
- Develop careful management strategies for afforestation projects.

Diversify land-use

The potential to protect biodiversity and store carbon can be significantly lessened when poorly planned schemes result in perverse incentives to replace native forests with plantations[33]. The establishment of forests must be balanced with the conservation of existing ecosystems. One promising strategy developed in Canada is the 'Triad' scheme, where forested land is divided into three sectors:

(A) Fully protected native forests;
(B) Sustainably managed and selectively logged native forest;
(C) Intensively managed plantation forest[17].

While biodiversity protection is emphasized in sectors A and B, sustainable production and harvest of timber in sectors B and C maximise carbon storage and deliver economic security to local communities[34].

Prioritise protection and reforestation

To maximise the amount of carbon captured by trees, protecting existing forests should be prioritised above establishment of new plantations. If all existing forests were to be cleared and converted into grasslands or croplands, this would significantly increase the concentration of carbon dioxide in the atmosphere by around 130–290ppm. This increase could not be balanced simply by planting new trees[35]. Assisted reforestation of native forests is a low-cost strategy that maximises rates of carbon storage since younger fast-growing native forests have greater rates of productivity than mature forests. For example, Latin America and the Caribbean have great potential for reforestation, following decades of intensive deforestation. In these areas, up to one-third of the land area could be reforested, capturing 8.5 gigatons of carbon (equal to 31.5 gigatons of carbon dioxide) from the atmosphere over the next four decades[36].

Develop specific local management strategies

There is no universal strategy for maximising the amount of carbon storage. Instead, management strategies should be tailored to each location. For example, managing the timing of harvest should consider both the age of the forest and the wood products it can yield. There is a trade-off between maximising carbon storage (since the growth rate of a forest changes with age) and economic gain (as larger logs from older trees are more valuable). Since there is no 'one size fits all' solution, policymakers need to incentivise careful management that considers not only carbon storage, but also the economic and environmental benefits of carefully selected harvested wood products[37].

Additionally, mitigating the risk of fire is an important consideration in landscapes where plantations are most vulnerable. To reduce the risk, it is important to plant a diverse range of native species with mixed ages and take risk-reducing measures, such as controlled low-intensity burning[38,39]). All afforestation efforts should consider the predicted changes to an ecosystem and susceptibility to fire before commencing[40].

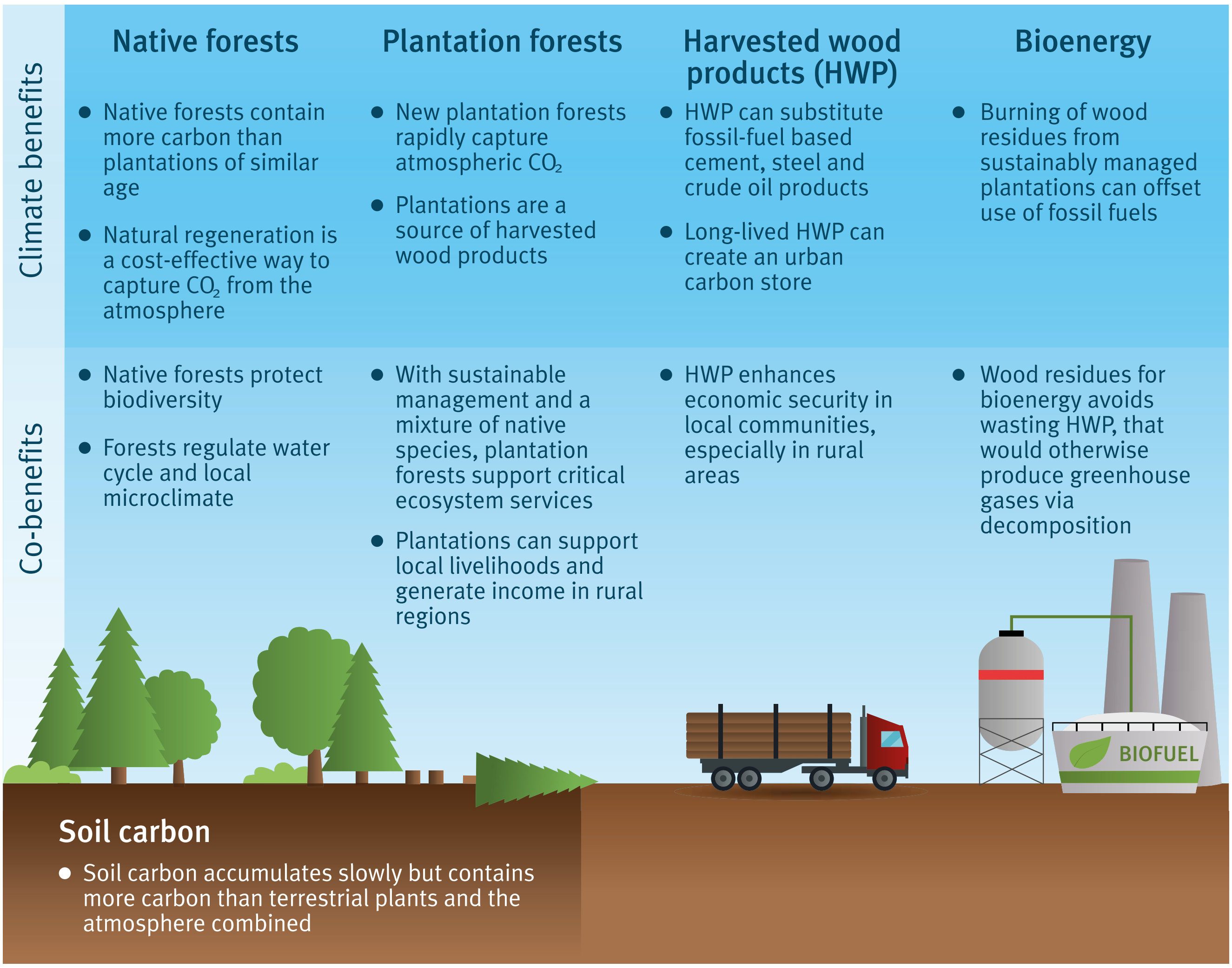

Figure 3: The benefits of large-scale tree planting, including using produced timber as a commercial product and energy source.

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Acknowledgements

Colin Prentice acknowledges funding from the European Research Council (ERC) under the European Union's Horizon 2020 Research and Innovation Programme (Grant Agreement No: 787203 REALM). Mathias Neumann acknowledges support from the Austrian Science Fund (FWF) Grant No. J4211-N29. We thank Stacey McCormack and Liam Holder for the development and production of the infographics as well as Liam Holder for his contributions to writing this paper and Simon Levey for his help in editing.

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Please cite this paper as:
Waring, B., Neumann, M., Prentice, I.C., Adams, M. Smith, P. and Siegert, M.J. (2020) What role can forests play in tackling climate change? Grantham Institute Discussion Paper #6. Doi: https://doi.org/10.25561/80271.

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