PEER-REVIEWED

Positive environmental impact of productive forest expansion on mitigating climate change and reducing natural and semi-natural forest loss

By Andrew D Cameron

Abstract | Afforestation and reforestation programmes are increasingly influenced by environmental policies favouring nature restoration often linked to the concepts of 'rewilding' and 'nativeness'. These strategies regularly prompt criticism of productive forestry associated with the use of non-native species and forest expansion oriented towards commercial production. While tree planting supporting biodiversity and nature protection is extremely important, this paper highlights the significant positive environmental impacts of productive forest expansion in achieving critical policy goals of reducing atmospheric CO_2 and meeting the growing global demand for sustainable wood products that in turn reduces pressure to exploit the world's remaining natural and semi-natural forests. The importance of non-native tree species in future afforestation and reforestation programmes is examined in the context of a rapidly changing climate and the need to increase the future resilience of forests. Implications of forest expansion on land availability are discussed.

Keywords: productive forests, climate change, timber extraction, offsetting, afforestation, reforestation, non-native species

Introduction

While productive forests are recognised as effective carbon sinks, as a source of a renewable natural material, and as providing a wide range of social and environmental benefits (e.g. Sedjo & Botkin, 1997; Pawson, 2013; Barua et al., 2014; Strange et al., 2019), productive forest expansion is viewed less favourably by some environmental organisations and media commentators, with criticism often focused on the use of non-native species and on tree planting oriented towards commercial timber production (e.g. Crane, 2020; Barkham, 2020; Reid et al., 2021). The narrative on forest expansion is increasingly influenced by the paradigms of 'rewilding' (broadly defined as minimal/no human intervention unless at the early restoration stage, leaving an area to nature as opposed to more active management, although other interpretations exist, e.g. Jørgensen, 2015) and 'nativeness' (use of species that arrived due to natural processes with no human intervention), with an expectation of limited – if any – timber production. Within the EU, established concepts of sustainable forest management and multifunctional forestry have seen a shift towards policies with a narrower focus on biodiversity and nature protection (Wolfslehner et al., 2020) raising concerns that future timber supplies will be compromised (Köhl et al., 2021).

Forest policy is also increasingly influenced by the need to address climate change, and is placing pressure on governments to transition to 'net zero' in carbon dioxide emissions. The role of the world's forests in climate change mitigation strategies was raised at the UN Climate Change Conference in Glasgow (COP26, 2021) highlighting the ongoing issue of carbon entering the atmosphere through deforestation (e.g. Woodwell et al., 1983; Cramer et al., 2004; Stern, 2007; Zarin, 2012; IPCC, 2019). Rising international

Top: Woodland and productive forestry in the Fort William area. Photo by Anna Saveleva on Unsplash.

demand for timber, at around 4% per year, will inevitably see a reversal from a global wood surplus to a deficit, potentially by the middle of this century (Churkina & Running, 2000), precipitating an expansion of logging in natural and semi-natural forests, including many of the world's most threatened tropical forests (Sedjo & Botkin, 1997; Indufor, 2012; Barua et al., 2014). Over 80m ha of primary forest have been lost since 1990, mainly from agricultural expansion, but logging is increasingly implicated (FAO, 2020a). If developed nations, as the biggest users of industrial wood products (in 2020 they constituted around half of total global wood production (FAO, 2021)), do not significantly increase domestic timber production, more will have to be imported, and this raises concerns over 1) the security of future timber supplies as global demand increases, 2) assurances that future imports come from sustainably managed forests, and 3) the 'carbon footprint' associated with increasing imports involving the transport of timber over long distances.

Imports of wood products into the EU may be restricted by a proposed regulation ('Fit for 55'—Delivering the EU's 2030 Climate Target on the Way to Climate Neutrality; Köhl et al., 2021) to minimise 'EU-driven' deforestation and forest degradation that is expected to come into force in 2023–24, requiring importers of timber, timber products and deforestation risk-related commodities to demonstrate not just their legality but that imported wood products are not associated with forest damage or loss (European Parliament, 2020). While it is unclear if this approach will be adopted elsewhere, it nevertheless underlines a future with potentially further restrictions on the type of wood products that can be imported and where they come from. There are already concerns over illegally logged wood from primary forests that frequently enters the international marketplace (e.g. Nellemann et al., 2018), and although forest certification has had a positive influence on sustainable forest management, nearly all the world's certified forests are in developed countries (87% in Europe and North America) with limited uptake elsewhere making it difficult to control exploitation (Xu & Lu, 2021).

Ironically, the growing demand for timber is influenced by environmental pressures, particularly in developed countries, to replace polluting or non-sustainable materials with wood products, and arguments around carbon and 'embedded energy' are increasingly used to support the greater use of wood. Architects and builders are using more wood products in building construction as part of climate change mitigation strategies to 'lock up' carbon in long-lived structures (FAO, 2016) with reductions in carbon emissions of around 20% and 60% possible by substituting timber for masonry and concrete respectively (Spear et al., 2019). Wood is an indispensable raw material in the packaging sector, with wood-based products such as paper and cardboard increasingly replacing oil-based plastic packaging (Hurmekoski et al., 2018). Advances in the production of biochemicals from wood allow potential substitution of oil-based products, including textiles, where wood-based fibres such as viscose result in lower levels of CO_2 emissions than the production of cotton or synthetic fibres (Rüter et al., 2016), and emerging technologies in extracting compounds from wood demonstrate the potential for jet fuel production from forest residues (Michaga et al., 2022).

Given the urgency associated with limiting the impact of climate change and reducing the destruction of natural/semi-natural forests associated with unsustainable logging, set against a background of increasing world demand for wood products, it is essential that both global and domestic benefits of productive forestry are better understood. This paper highlights the role of productive forest expansion in meeting crucial international policy goals associated with climate change mitigation and environmental protection. It considers the importance of non-native tree species in future afforestation and reforestation programmes against a background of a rapidly changing climate and the need to increase the resilience of forests from biotic and abiotic threats. Land availability and environmental constraints associated with productive forest expansion are discussed.

Role of productive forests in limiting natural forest loss

While growth of European forests currently exceeds production by a considerable margin, concerns over climate-induced damage, primarily through a combination of drought stress and insect attack, have resulted in many European countries revising down their production forecasts (Forest Europe, 2020). Since 2018, more than 2.5% of Germany's total forest area has died due to drought-induced stress and associated beetle attack caused by a warming climate, raising concerns that dwindling industrial wood supplies will place pressure to exploit forests elsewhere around the world (Popkin, 2021). Pressures to increase the area of 'protected forests' and 'strictly protected forests' within the EU will further reduce future timber availability (Köhl et al., 2021). While a loss of productive forest area is unlikely to affect exports in the short to medium term, as felling volume gets closer to increment if exports continue to rise, sustainability of future timber exports from Europe may be impacted. This raises concerns particularly for high-importing countries such as Britain – the world's second biggest importer of wood products – about where its wood will be sourced in the future. The situation is likely to be made

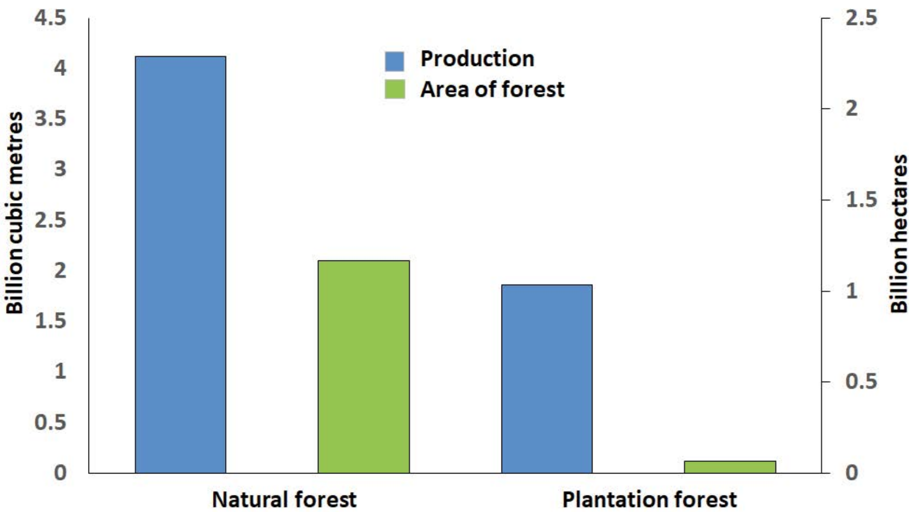

Figure 1. An approximate estimate of global industrial roundwood production from natural and productive plantation forests, illustrating the area of forest required to meet current demand (adapted from Sedjo & Botkin, 1997; FAO, 2020b).

worse by the intention of Russia to stop exporting softwood logs from the east of the country, placing greater pressure on China's extensive wood processing sector (Douzain, 2021). China, as the biggest global importer of wood products, will have to replace this supply of timber from elsewhere in the world, and Europe is one potential source, placing further pressures on international timber availability (Douzain, 2021).

Productive plantation forests are hugely significant in international timber trade, accounting for one third of global industrial timber supply from only 3% of the total global forest area (FAO, 2020b). An approximate estimate of the area of natural and productive plantation forest required to supply current global industrial timber production is shown in **Figure 1**. The existing rate of expansion of productive plantation forests is not sufficient to keep pace with global industrial timber demand, which is expected to have more than doubled by 2050, by which time productive forests will supply less than one quarter of world demand for industrial timber (Indufor, 2012) (**Figure 2**). A global shortfall of industrial timber will have to be met increasingly from natural and semi-natural forests (Indufor, 2012; Köhl et al., 2021). Forests, particularly in tropical and semi-tropical regions, are already under severe pressure from human activity, and with increasing international demand for timber pushing up prices, an increase in illegal logging is predicted, resulting in forests being unable to support increased production targets due to unsustainable timber extraction (Barua et al., 2014).

Production of marketable timber from natural forests is low, ranging from about 1–3 m³/ha annually (Sedjo & Botkin, 1997) and requires extensive areas of forest to be logged to achieve an economic timber output that in turn causes significant environmental damage during the process of timber extraction (Barua et al., 2014). Supplying the annual global use of industrial timber, estimated at approximately 6bn m³, would require 2–6bn ha of natural forest to achieve. With the global area of natural forest at around 3.75bn ha (FAO, 2020b), producing industrial timber at the current level of demand would likely exceed available production in all the world's remaining natural forests. Productive forests, on the other hand, combine high productivity and focused operational activity in relatively small areas, reducing the 'environmental footprint' compared with the more expansive and damaging timber extraction from natural forests (Barua et al., 2014). Productive forests typically produce at least ten and up to 20 m³/ha annually (higher yields are not uncommon) (Sedjo & Botkin, 1997); that would require 0.3–0.6bn ha of forest to meet the entire current global use of industrial timber, a fraction of what would be needed from natural forests. Achieving future global roundwood demand without additional exploitation of natural and semi-natural forests will require a significant expansion of productive forests well above current levels and would allow more of the world's remaining natural forests to be devoted to wildlife protection and habitat conservation (Sedjo & Botkin, 1997).

Importance of productive forests as carbon sinks

Total global carbon stocks in forests have declined from 668 Gt in 1990 to 662 Gt in 2020 (FAO, 2020b). Although tree planting has increased in many countries in recent years, limiting global warming to 1.5°C above pre-industrial levels, as stated in the Paris Climate Agreement of 2016 (United Nations, 2016), will urgently require mitigation strategies to be put in place, including significantly increasing forest carbon sinks (Grassi et al., 2017). A report by the Intergovernmental Panel on Climate Change recommended an increase of 1bn ha of forest to limit global warming to 1.5°C by 2050 (IPCC, 2019).

Most of the stored carbon in established forests is held within the living biomass and soil organic matter. Productive species achieve greatest absorption of incoming solar radiation – and therefore carbon capture potential – at canopy closure, which can typically occur in less than 20 years (Jarvis and Linder, 2007). At harvesting, soil carbon stocks (and a large proportion of nutrients) can be replenished if most of the residues (e.g. branches, offcuts, tree stumps) are retained on site (Jarvis & Linder, 2007). Tree planting on barren land (sparsely vegetated/eroded), especially with conifers, has been found to be associated with a significant increase in soil organic carbon sequestration in mineral soils (Bárcena et al., 2014). Soil type is important, since afforestation of deep peats involves extensive drainage, lowering the water table, with a resulting increase in CO_2 emissions (Sloan et al., 2018). In many countries, there is an increasing presumption against afforestation on deep peats or in areas that would potentially damage wider hydrology or wetland habitats (e.g. Bragg & Lindsay, 2003; Forestry Commission, 2017; Friggens et al., 2020).

While some authors claim that planting native broadleaved species and rewilding are more effective in climate change mitigation than establishing productive forests (e.g. Lewis et al., 2019), numerous studies show that productive forests are significantly more effective at removing and storing atmospheric carbon than environmental tree planting (e.g. Cannell & Dewar, 1995; Nijink, 2010; Leskinen, 2018; Forster et al., 2021). Productive forests will continue to deliver mitigation long into the future, when environmental

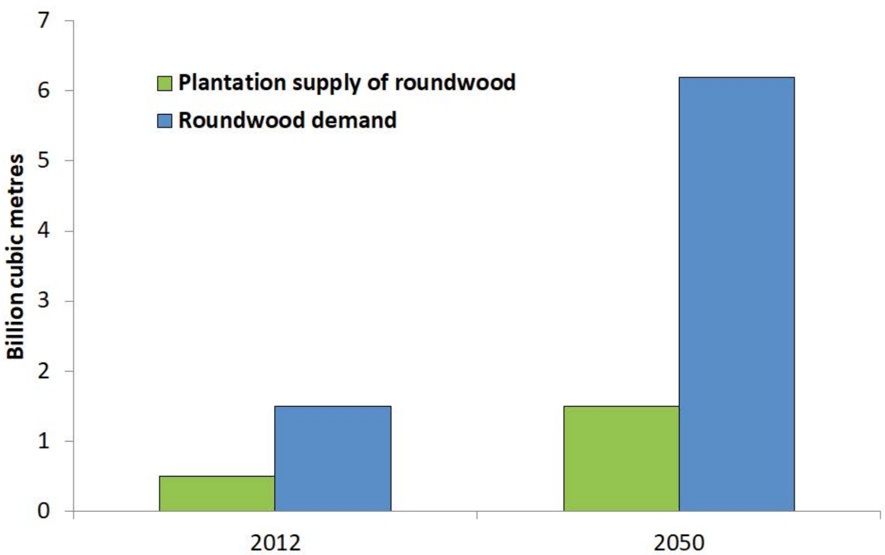

Figure 2. Predicted increase in global demand of industrial roundwood and associated availability from productive plantation forests (adapted from Indufor, 2012).

forests will have reached their peak capacity (Forster et al., 2021). Indeed, the growth potential of productive forests is likely to be maintained or even increased as the climate changes, highlighting the importance of these forests as significant carbon sinks (Jarvis & Linder, 2007).

A substantial part of greenhouse gas mitigation potential of productive forests involves the fate of the harvested wood, defined by four life cycle stages (production, use, cascading (reuse) and end-of-life) (Leskinen et al., 2018). Taking account of both forest growth and use of the harvested wood, a study based on these life cycle stages over a 100-year time horizon found that newly planted productive Sitka spruce (*Picea sitchensis* [Bong.] Carr.) forest over two harvests supported up to 269% more greenhouse gas mitigation potential than newly planted broadleaf conservation forests and 17% more than newly planted fast-growing conifer forest left unharvested (Forster et al., 2021). Substitution benefits are gained from reduced emissions during production and end-of-life stages, particularly when post-use wood is recovered for other purposes (Leskinen et al., 2018). High productivity is also a significant factor in greenhouse gas mitigation (Doelman et al., 2020; Forster et al., 2021) and is consistent with other studies indicating that expansion of the forest area using fast-growing species is the most cost-effective way to sequester carbon (e.g. Stern, 2007; Nijnik, 2010). This was highlighted in a study where costs of planting and managing productive forest were estimated at between £3 and £4.50 per tonne of CO_2 sequestered (harvested wood not included) depending on optimistic or pessimistic calculations respectively, whereas removing atmospheric carbon using carbon capture and storage (CCS) technology was estimated to cost a minimum of £50 per tonne of CO_2 (Openshaw, 2016).

Non-native tree species in a changing climate

Some European regions have relatively high natural tree species diversity (Petit et al., 2003) whereas it is very limited in others, mainly due to historical glaciation events (Svenning, 2003), and are associated with a history of using non-native species. This is particularly true of Britain and Ireland, where non-native tree species have been introduced to supplement the limited tree flora. Globally, conifers have long been favoured due to their site adaptability, good growth and versatile wood properties. Coniferous wood (softwood) is preferred over broadleaved wood (hardwood) due to its lightness and high strength to weight ratio, making it very suitable for construction, and its long fibres are ideal for paper-based products (e.g. Dinwoodie, 2000).

The immediacy of climate change has renewed the debate on appropriate tree species to use in productive forests, particularly with a potential increase in susceptibility to more severe climatic events and attack by pests and diseases. While native species have an advantage of inherited acclimatisation to their environment over a long time, climate change is predicted to occur more quickly than the rate of natural adaptation and migration that will see many species unable to survive in regions where they have long thrived (Aitken et al., 2008; Seidl et al., 2017). For this reason, there are risks in attempting to restore past conditions, since climate change forces forests to adapt to new environments (Seidl et al., 2014). In some circumstances native species appear to be more vulnerable to environmental damage than introduced species (e.g. Battipaglia et al., 2009), although both native and non-native species can succumb to novel pests. This is not a reason to stop the restoration and expansion of endangered native forests; however, dealing with the imminent environmental crisis associated with climate change will require new thinking regarding future afforestation. Climate-related damage to forests is a 'general forest problem' and not an issue specific to managed productive forests (Forzieri et al., 2021; Hazarika et al., 2021).

The preference for native species and locally sourced reproductive material within the EU has held sway in afforestation and reforestation programmes for a long time (e.g. MCPFE, 1993). However, the use of non-native species better adapted to a changing climate, and intermixing native and non-native species, has been widely discussed in Europe (Bolte et al., 2009; Lindner et al., 2010; Jandl et al., 2019) and is seen as an important part of adaptive forest management, given an uncertain future climate and concerns over threats to forest trees from novel pests and diseases (e.g. Spathelf, 1997; Johann, 2006). This uncertainty has highlighted the need not only for a greater range of more resilient species to be used but the establishment of species mixtures (e.g. Pretzsch, 2009; Mason and Connolly, 2018; Cameron, 2015; Isbell et al., 2015; Pretzsch et al., 2017; Popkin, 2021). This is particularly relevant to countries such as Scotland and Ireland, where a single species – Sitka spruce – dominates the productive forest area. Arguments supporting the use of mixtures in productive forest stands is based on the likelihood of one of the species in a mixture surviving climate-related damage (biotic and abiotic), limiting the potential environmental and economic loss if only a single species were present (e.g. Cameron, 2015). The diversification of species in productive forests is already taking place in parts of Germany, where pure Norway spruce (*Picea abies* (L.) Karst.) forests are being converted into mixed stands by introducing the more drought-tolerant North American Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco) (Spathelf et al., 2009). Other North American species being considered, which have not only survived the Central European droughts but have been found to grow well, are red cedar (*Thuja plicata* D.Don), incense cedar (*Calocedrus decurrens* [Torrey] Florin) and western hemlock (*Tsuga heterophylla* [Raf.] Sarg.) (Popkin, 2021).

Discussion

It is widely accepted that the climate is changing, with a greater frequency of extreme droughts, wildfires, flooding, and biotic attacks experienced in many regions of the world. Mitigation strategies will require major reductions in CO_2 entering the atmosphere (e.g. burning fossil fuels, intensive agricultural systems, destruction of natural forests), and reduction of the levels of CO_2 already in the atmosphere (carbon capture). Productive forests need to be part of the strategy to reduce CO_2 emissions, partly as carbon sinks and by reducing the destruction of the world's remaining natural forests through timber extraction offsetting. Anecdotally, people are supportive of using more environmentally sustainable wood products to replace non-renewable, often polluting materials, yet are often averse to the productive forest expansion needed to supply the wood they want. Without significant expansion of productive forests, more timber products will have to be imported, and these will increasingly and inevitably be sourced from natural and semi-natural forests. Following the COP26 global agreement to address the loss of the world's forest, wealthy industrialised nations can no longer continue to 'export' the environmental consequences of where their wood products come from while at the same time using large tracts of potentially productive land to pursue a range of amenity-related interests.

Discussions on productive and environmental tree planting are too often presented as competing options, but both have a place in our landscapes. Productive tree planting is not the 'ideal' or only solution to reducing atmospheric CO_2 levels, nor should it be used as a substitute for reducing fossil fuel use; nevertheless, afforestation programmes are widely seen as a 'natural' way to sequester carbon from the atmosphere and are a critical part of a wider strategy in addressing the challenge of climate change (e.g. IPCC, 2018; Bastin et al., 2019). While rewilding may have the appeal of leaving areas of forest to nature, active management and periodic harvesting reduce the risk of environmental damage and safeguard carbon stocks within wood products while climate change increases environmental risks to old unmanaged forests (Forster et al., 2021).

The scale of forest expansion promised by governments following COP26 will require significant investment, and establishing trees is costly. If forest expansion is primarily based on environmental tree planting without any realistic economic return, then large-scale afforestation programmes as part of climate change mitigation strategies will not happen without a substantial input of taxpayers' money, and this may not be so readily available with many competing demands on government funding. While carbon offset schemes provide incentives to plant trees to compensate for unavoidable greenhouse gas emissions from elsewhere, these arrangements have raised concerns that such investments are symbolic and not sufficiently robust to deliver credible decarbonisation (e.g. Wright & Nyberg, 2017). Achieving a significant expansion of productive forest will require major investment from the commercial sector supported by existing incentives such as planting grants and tax measures.

Expansion of productive forests will inevitably create tensions with other land uses, particularly agriculture. Since more intensive agricultural production in developed countries occurs on better quality farmland, it is generally recommended that afforestation should primarily take place on less productive or marginal farmland and otherwise overgrazed/degraded land where there is the potential for a high timber production value on land poorly suited for agriculture (e.g. Sedjo & Botkin, 1997; Kauppi et al., 2018). This was demonstrated in a study in southern Scotland where the costs of maintaining hill sheep farming in Less Favoured Areas (LFA) (defined by combination of poor climate, soils and terrain, lower yields, higher production, and transportation costs) was found to require a direct payment subsidy of around 60% of output for survival, while productive forestry on the same land received a small grant contribution of around 3% of output, although the authors point out that these values will vary among regions (SAC Consulting, 2014).

From a Scottish perspective, research suggests that around 2.2m ha (~28% of non-forested land) is potentially suitable for afforestation given certain environmental constraints (Towers et al., 2006) and concurs with a more recent estimate of 2.3m ha (Burke et al., 2021). Towers et al. (2006) emphasised that this level of afforestation would have minimal impact on agricultural production and would not impinge on areas designated for their environmental values (e.g. native pine areas, Atlantic oakwoods, blanket bog/wetland ecosystems, SSSIs, National Nature Reserves). Even if all the potentially suitable areas for afforestation in Scotland were planted while taking into account other factors such as landscape/recreation/habitat and needs of local communities, a vast area of Scotland would remain as 'wildscape'.

Given the scale of the environmental crisis associated with climate change, and pressures to achieve 'net zero' carbon dioxide emissions, land that is suitable for productive forestry should be preferentially used for this purpose, with environmental forest expansion or rewilding mainly concentrated on areas that are largely unsuitable for productive forestry and agriculture. Both these scenarios would require recognition of local community interests. Even where productive forest expansion takes place, development of wildlife corridors, riparian zones, and open spaces that are the norm in forest management would allow greater habitat connectivity between areas set aside specifically for environmental protection. Interestingly, rewilding could be advanced to a much greater extent than at present in Scotland (and elsewhere) – and at a fraction of the cost of environmental tree planting schemes – by advocating for legislative control to greatly limit the density of deer populations, enabling the natural expansion of native forest (MacMillan, 2022).

Environmental organisations should not fear productive forest expansion, since it is highly regulated to ensure that new and existing areas of forest are of the highest standard in terms of design, environmental protection, and provision of recreation, with sustainability a central feature of forest management. Furthermore, the recreational and wider amenity value of forests to the average citizen are unlikely to be influenced by whether forests are productive or not. This was underlined in a recent survey in Scotland in which 90% of the public supported productive forest expansion (FLS, 2021).

Well-implemented commercial forest management has little or no long-term environmental impact on water quality and freshwater ecology (e.g. Binkley & Brown, 1993; Nisbet et al., 2002; Shah et al., 2021). Even newly established areas of forest quickly provide a wide range of ecosystem services including improved water quality and recreation (Vesterdal et al., 2002; Zandersen et al., 2007). The establishment of productive forests can also provide natural flood mitigation (e.g. FAO, 2005; Nisbet, 2015), a role that needs to be better recognised given the increased incidence of severe flooding. While the use of non-native species continues to be criticised with the implication of poor biodiversity, there are numerous studies demonstrating that productive forests of non-native temperate trees sustain a level of biodiversity equivalent to that in planted forests of native species (e.g. Humphrey et al., 2000; Sax et al., 2005; Smith et al., 2008; Quine & Humphrey, 2010; Irwin et al., 2014; Confor, 2020). Over time, well managed productive forests can take on certain characteristics of 'old-growth' forests if longer rotations are adopted (Oliver & Larson, 1996). Nevertheless, protecting and expanding existing areas of natural and 'old-growth' forest must remain a key part of environmental management strategies.

Achieving significant increases in afforestation will require governments to ensure opportunities for productive planting are not delayed through overly bureaucratic processes with approval primarily based on why productive planting *cannot* take place, while maintaining public trust in the planning process. It is essential that productive tree planting is sufficiently incentivised with financial aid scaled with carbon capture potential to encourage planting with optimum mitigation value. All new afforestation programmes should include a 'carbon capture index' linked to their climate mitigation potential, providing governments, policy makers and the public with a measure of the value of 'green investments' towards the goal of reducing atmospheric carbon.

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