# ASSESSMENT OF THE BENEFITS OF SUSTAINABLE FOREST MANAGEMENT

Drax Power Limited

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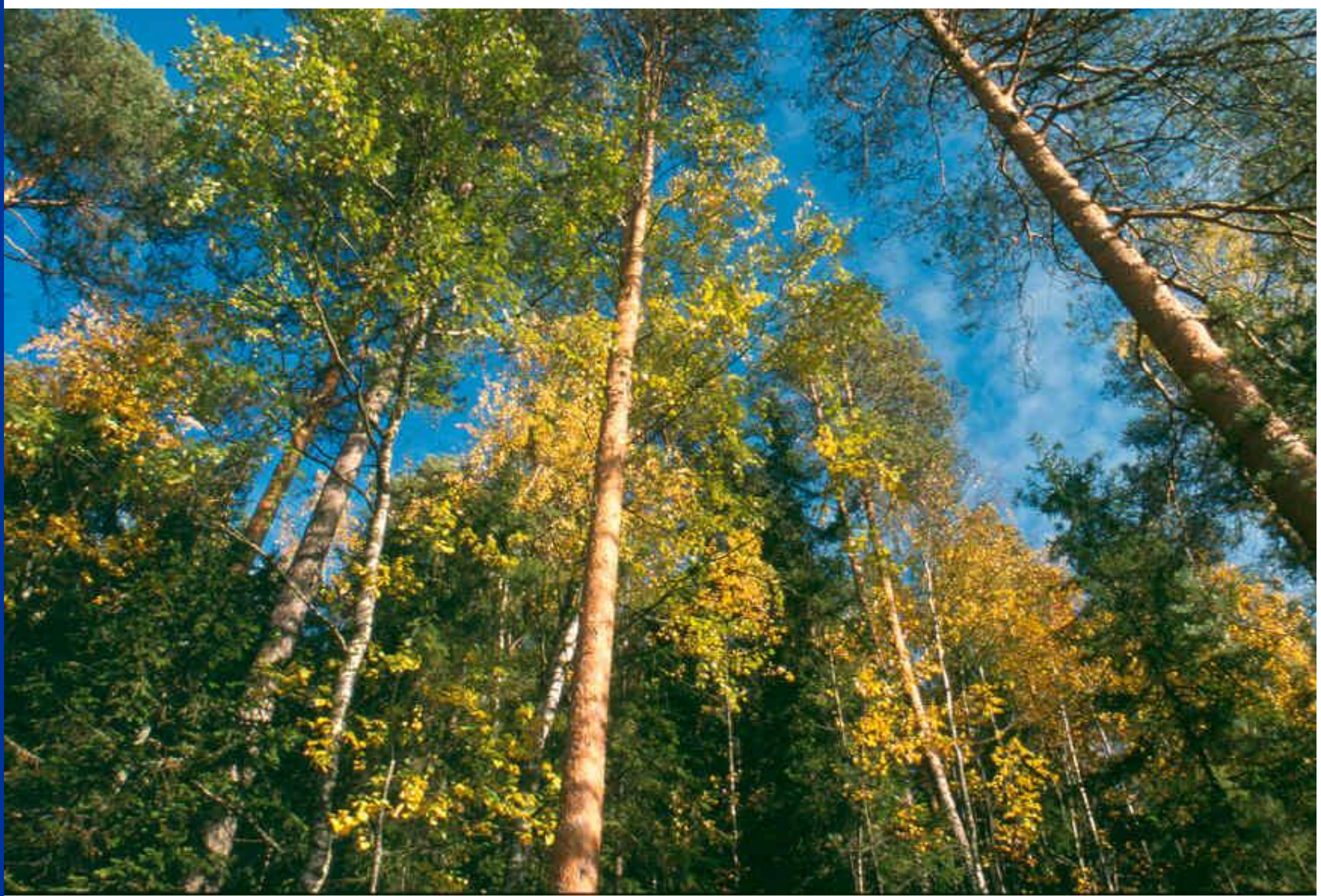

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# DISCLAIMER

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# EXECUTIVE SUMMARY

Drax Power Limited has engaged Pöyry Management Consulting (UK) Ltd to build on the Forest2Market study of historical trends in the forestry industry of the US South previously commissioned by Drax Group, the National Alliance of Forest Owners, and the U.S. Endowment for Forestry and Communities. The results of this are contained within this report.

### *Introduction*

The FAO has predicted that global wood demand will have more than doubled in the 25 years between 2005 and 2030. To meet this increasing demand, forests must be managed in a way that allows increased productivity while maintaining the large number of environmental and social benefits they provide, such as carbon sequestration, wildlife habitat, water management, and recreation.

This can be achieved through sustainable forest management, with wood from such forests also representing a fully-renewable resource, from which by-products can be used to generate renewable energy. This report discusses the positive impacts of sustainable forest management, focusing on improvement of growth and carbon storage in forests, as well as the benefits to social, environmental, and economic systems that it can offer.

To understand the consequences of abandoning stands which have previously been managed the absence of forest management has also been considered, and four case studies are presented to illustrate how sustainable forest management is being implemented.

### *Forest management to increase productivity*

In order to meet the predicted increase in demand for wood, it will be necessary to not only increase the afforested area, but also to increase the amount of wood that grows in existing forests. Sustainable forest management, which increases environmental, social, and economic benefits consider both the present and the future, can help to achieve this.

Forests sequester carbon during growth, and some of the factors impacting this growth can be adjusted to increase both growth and carbon sequestration. Examples include the use of fertilisers to supplement soil nutrients, understory management, and thinning forest stands to reduce competition and increase nutrient and light availability for growing trees.

Forest management also facilitates growth improvements before forests are even planted through the use of improved genetic material either through breeding programs or clonal propagation. Additionally, sustainable management should ensure that species are matched to suitable sites and are planted in a way so as to maximise growth and carbon sequestration.

Productivity increases in regions with sustainable forest management have resulted in forest growth that greatly exceeds volumes removed by harvesting, as is observed in all four of the case studies. Thus, the volume of trees and stored carbon is increasing in regions with sustainable forest management while at the same time allowing for wood production to increase.

### *Benefits of forest management following natural disturbances*

Forests can be damaged or lost due to natural disturbances such as fire, wind, and pests and diseases. In North America alone the area damaged by fire often exceeds 3 million hectares in a year, and the European Union reports approximately 10 million hectares is damaged by natural disturbances each year. This damage can lead to reduction in forest growth and associated carbon sequestration.

Sustainable forest management has been shown to be an effective method to counteract these risks:

- Fire damage risk can be reduced with understory management, thinnings, and creation of fire breaks when applied appropriately.
- Wind damage risk can be reduced by using wind resistant species, adjusting rotation length and harvesting plans in areas that regularly have high winds.
- Pests and diseases can be minimised through the use of thinnings to increase stand vigour and resilience to disease.

Forest management has also been shown to increase the speed of recovery in stands following damage, and may lead to damaged wood to being used rather than decomposing and releasing stored carbon back into the atmosphere.

### *Wider potential benefits of forest management*

Beyond increased growth and carbon sequestration, managing forests for wood production leads to job and income creation: both directly in the forest management and throughout the associated forest value chain. The World Bank states that the formal timber sector contributes 600 billion USD to the global economy, and is responsible for 54.2 million jobs. In particular, forest management is of benefit to rural economies, which currently may struggle with aging populations and low employment rates.

Additionally, sustainable forest management has been shown to have notable benefits in the developing world. Reduced firewood dependence, and improved health (partly through the ecosystem services forests provide) have been recorded, and many certified plantations in the developing world have social development plans including education, healthcare and primary forest protection through engagement with local communities.

The recreational value of forests should also be acknowledged and forest management can help facilitate recreational access through creation of more forest areas near to populations or through the development of roads and trails.

Lastly, active forest management can reduce pressure on primary or natural forests, and in some cases facilitates greater protection of these natural resources due to greater engagement with forest issues by communities.

### *Criticism and of forest management and mitigation of negative impacts*

Criticism of forest management is often a result of the wrong management techniques being applied, leading to negative impacts. The use of scientific, evidence based actions through sustainable forest management can minimise these negative impacts. In many cases consideration and actions to avert such negative impacts are built into the process and controls implemented at national and regional levels.

As an example, silvicultural practices such as using chemicals for fertilisation, and pest control are commonly pointed to as potential negative aspects of forest management. While their use is likely to continue to be necessary in maintaining forest productivity, the prevalence of certification schemes has led to increasing regulation and control of these chemicals to ensure sustainability. Additionally, studies which have considered the emissions associated with silvicultural practices have found that the gains in growth and carbon storage in soil, pulp and saw timber products outweigh the emissions from fertiliser use and do not lead to large increases in carbon payback time.

Plantation monocultures are another area of forest management with negative connotations, with criticism of the lack of species and bio diversity and the associated increased susceptibility to pests and disease. Modern plantations must be economically viable to be sustainable, which is often only achievable through the economies of scale afforded by monocultures. However, modern plantations are often established on degraded land, or former pasture (as is the case in Uruguay) and represent a significant improvement in terms of carbon storage over the previous land uses. Sustainable plantation management will also take into account the wider landscape, even enhancing biodiversity by providing for protection of sensitive sites and creating wildlife corridors between areas of natural forest.

Using heavy machinery in harvesting can also be associated with negative opinions. Machinery can compact forest soils, increasing runoff and erosion, and can increase carbon emissions both through its use and through soil disturbance. However, it is important to note that mechanised harvesting is the safest and most efficient means of felling trees, meaning that mechanised clearfelling will remain a part of active forest management to meet increasing demand for wood. The utilisation of appropriate equipment and operating practices should be applied to mitigate any potentially negative effects: by ensuring the scale of harvesting is proportionate to the landscape, and machines used minimise disturbance.

### *Consequences of the absence of forest management*

While there is the potential of some negative impacts from forest management, which can largely be mitigated through the use of the right management techniques, an absence of forest management would lead to more significant negative impacts. Such a scenario is one in which all active management would stop, and forests would be left to grow, develop, and die naturally. It is sometimes referred to as 'shut-the-gate' forestry.

If this were to be adopted on a large scale, it would imply a drastic change to forests and significantly reduce or remove forest industry. This in turn would result in greater emissions associated with the use of more carbon intensive materials in the place of wood. On balance it is unlikely that such a drastic measure would be taken globally, but this illustrates that the absence of forest management in itself is not a sustainable proposition.

Studies have shown that while mature unmanaged stands could represent a considerable store, the rate of carbon sequestration is much less than in young actively managed stands, and unmanaged stands may even emit carbon due to natural mortality or disturbances such as fire, wind, or disease. The increased rate of sequestration in managed forests therefore means that managed stands will sequester more carbon over multiple rotations than mature unmanaged forests will during the same time period.

### *A spectrum of forest management*

Based on this evidence it is clear that sustainable forest management activity must vary over the spectrum of forest types:

- Primary forests which represent a large carbon store and a high biodiversity value should not be greatly disturbed. Sustainable management should aim to protect and maximize these environmental values.

- Plantations will produce the greatest overall benefit through active management to increase yields and thus carbon storage. Consideration of the role plantations play in the wider landscape is also important in how they are managed.

- Semi-natural forests sit in between these first groups and must be evaluated based on the history of use and the value of biodiversity and stored carbon, to determine what form of management is most appropriate.

### *Case Studies*

The following case studies highlight how sustainable forest management has been implemented in the past, and the benefit it has had.

#### *US South*

The US South demonstrates how moving to a sustainable forest management system in an existing forest area can increase above ground forest carbon stocks. Historically, harvesting in this region was exploitative, with selective harvesting of 'high-grade' areas of natural forest to remove the best timber, leaving deteriorating stands of poor genetic material which were expected to naturally regenerate. However, over the past 70 years this has transitioned to more intensive management with active planting of improved genetic material. The result of this has been an increase in both wood production, and standing forest volume, whilst still maintaining the area of forest cover and the associated ecosystem services.

#### *Finland*

Forest production plays a significant role in the country's economy and it has a long history of forest management, considered by many to be at the forefront of sustainable forestry practices. These practices have been developed based on decades of research, which still continues to be developed. Improvements to forest management practices are effectively communicated and then implemented by the very high number of private forest owners, and this has resulted in continuously increasing forest carbon stores in Finland's forests, which still meet the demands of domestic producers and the export market alike.

#### *United Kingdom*

As recently as the beginning of the last century, forest cover in the UK was at a low point representing just ~4.7% of total land area. It has since recovered due to a range of public and private afforestation efforts to a current level of ~13%. While this has not been achieved entirely with sustainable forest management, the UK has put a concerted effort into encouraging increased active forest management to foster a position where forest land cover includes a diversity of habitats, species, and age classes, thus providing a wide range of benefits. All the while, this management has helped to ensure high productivity and an increasing standing forest volume from a limited area of land.

#### *Uruguay*

Uruguay has experienced a rapid development of its forest industry in recent decades which has drastically increased the forest area and forest carbon stock. There have also been concerted efforts to establish suitable sustainable forest management practices to achieve maximum growth potential. Simultaneously this has prevented deforestation of natural forests in the country. The development of the forest industry in Uruguay has happened more recently than in other regions and primarily under basic economic principles, but has nonetheless resulted in extensive forests managed under sustainable practices.

# 1. INTRODUCTION

Drax Power Limited has engaged Pöyry Management Consulting (UK) Ltd to build on the Forest2Market study, 'Historical Perspective on the Relationship between Demand and Forest Productivity in the US South' previously commissioned by Drax Group; the National Alliance of Forest Owners; and the U.S. Endowment for Forestry and Communities. The Forest2Market study found that over the last 60 years, as demand for forestry products has increased, the productivity of forests and the amount of carbon stored in forests in the US South has also increased.

In this report, Pöyry discusses more widely the positive impact of sustainable forest management focusing particularly on improvement of growth and carbon storage in forests. Additionally, wider benefits to the social, environmental, and economic systems are considered where appropriate, sustainable forest management occurs.

Additionally, the absence of forest management is considered as a comparison to show where the absence of forest management may be appropriate.

To practically demonstrate the wide application of sustainable forest management, four case studies are put forward. These represent a variety of examples of the impact of sustainable forest management covering multiple geographic, political, and environmental conditions:

- US South
- Finland
- United Kingdom
- Uruguay

This report focuses on semi-natural managed forests as well as plantations. Natural, old-growth forests are not considered extensively here, due to the fact that sustainable forest management practices would exclude such forests due to these forests' wider values outside of wood production (social and environmental benefits).

Evidence for the discussions is based on both peer reviewed literature and Pöyry's international forestry knowledge base to ensure thorough coverage of the impact of sustainable forest management.

### *Forest products*

While this report is concerned with in forest carbon, it is important to consider the fate of carbon that is removed from the forest. Wood coming from managed forests may either provide further storage in forest products (which can also lead to substitution versus more carbon costly products e.g. concrete), or in the substitution effect versus fossil fuels for energy production. Exclusion of this store of carbon in analysis can result in invalid conclusions regarding the benefits of forest management[1], and acceptance of this as a carbon pool has been internationally recognised since COP17 Durban in 2011. There is additionally a large body of peer reviewed literature which addresses the carbon benefits of forest products and fossil fuel substitution through methods such as life cycle

[1] Lippke *et al.*, 2010, **Characterising the importance of carbon stored in wood products**, *Wood and Fibre Science* ***42(CORRIM Special Issue)***

assessment. Consideration of this in detail is beyond the scope of this report; however it is discussed where relevant.

# 2. FORESTRY CONCEPTS AND DEFINITIONS

A wide variety of definitions have been applied in forest assessment. Discussions of what is a 'forest' are common: Indeed the IPCC report on Land Use, Land-Use Change, and Forestry (LULUCF)[2] discusses the difficulty in defining a forest and what the impact of the definition will be on the amount of land included in the carbon accounting for Kyoto Protocol reporting. It is also common for definitions to be influenced by management or policy objectives with some factors in definitions being less important than others depending on the objectives[3].

The intervention involved in managing forests occurs on a spectrum and many of the terms may overlap or be difficult to separate in a meaningful way. However, In order to provide as much clarity as possible with regards to the terms used throughout this report, we present common definitions (taken from sources relevant to this report) as well as discussing how terms may be related.

## 2.1 Forestry Terms

Throughout this report we use the definitions as provided in Table 1.

**Table 1: Forestry Term definitions**

| *Term* | *Definition* |
|---|---|
| Plantation forest | Forest of either native or introduced species established by planting or seeding[4] |
| Natural forest | A forest composed of indigenous trees and not classified as a forest plantation[5] |
| Primary forests | Naturally regenerated forest of native species, where there are no clearly visible indications of human activities and the ecological processes are not significantly disturbed[6] |
| Semi-natural forests | Forest/other wooded land of native species, established through planting, seeding or assisted natural regeneration[7] |

[2] IPCC, 2000, **IPCC Special Report: Land Use, Land-use Change and Forestry**

[3] Chazdon et al., 2016, **When is a forest a forest? Forest concepts and definitions in the era of forest and landscape restoration**, *Ambio **45***

[4] Carle & Holmgren, 2003, **Definitions related to planted forests,** *Paper presented at UNFF Inter-sessional Expert Meeting International Steering Group on "The Role of Planted Forests in Sustainable Forest Management - Maximizing Planted Forests' Contribution to SFM". Wellington, New Zealand*

[5] UNFCCC, 2006, **United Nations Framework Convention on Climate Change: Handbook**

[6] FAO, 2015, **Forest Resources Assessment (FRA) 2015: Terms and Definitions**

[7] FAO, 2005, **Global Forest Resources Assessment Update 2005: Terms and Definitions**

| | |
|---|---|
| Naturally regenerated forest | Forest predominantly composed of trees established through natural regeneration[6] |
| Active forest management | Attaining desired forest objectives and future conditions through forest management practices and operations such as harvesting, thinning and silviculture |
| Afforestation | Direct human-induced conversion of land that has not been forested for a period of at least 50 years to forested land through planting, seeding and/or the human-induced promotion of natural seed sources[8] |
| Reforestation | Direct human-induced conversion of non-forested land to forested land through planting, seeding and/or the human-induced promotion of natural seed sources, on land that was forested but that has been converted to non-forested land[8] |

It is possible to see how some of these definitions overlap and interact in Table 2. It is apparent that only primary forests have no human activity, with the remaining forest types on a spectrum of human intervention. Thus, while efforts are made to clarify the differences between forest types, the distinction between them will often be a result of the perspective of the classifier[9].

[8] UNFCCC, 2006, **Report of the Conference of the Parties serving as the meeting of the Parties to the Kyoto Protocol on its first session,** *Annex: Definitions, modalities, rules and guidelines relating to land use, land-use change and forestry activities under the Kyoto Protocol*

[9] FAO, 2000, **The Global outlook for future wood supply from forest plantations**, *Working Paper*

**Table 2: Definition hierarchy overview**

| Natural Forest | | | Planted Forests | | |
|---|---|---|---|---|---|
| **Primary** | **Naturally regenerated forests** | **Semi-Natural** | | **Plantation** | |
| | | ***Assisted natural regeneration (through silvicultural practices)*** | ***Planted Forests*** | ***Productive*** | ***Protective*** |
| Forest of native species, where there are no clearly visible indications of human activities and the ecological processes are not significantly disturbed | Forest of naturally regenerated native species where there are clearly visible indications of human activities | Weeding, fertilising, thinning, selective logging | Forest of native species, established through planting, seeding, coppice | Forest of primarily introduced and native species, established through planting or seeding mainly for production of wood or non-wood goods | Forest of native or introduced species, established through planting or seeding mainly for provision of services (flood protection, hillside stabilisation etc.) |

Source: FAO, Pöyry

## 2.2 Sustainable forest management (SFM)

There are a number of different definitions of sustainable forest management (Table 3). It is possible to see that throughout the definitions social, environmental and economic impacts are mentioned. Time scale is also an important factor in many of the definitions, with most referring to an ongoing process into the future either implicitly or explictly.

It is therefore to be understood that while there is no common definition of sustainable forest management, it will not be occurring if all of these factors are not being considered in the management of forests.

**Table 3: Sustainable forest management definitions**

| *Source* | *Definition* |
|---|---|
| FSC | “A forest that is managed in a way that preserves the natural ecosystem and benefits the lives of local people and workers, all while ensuring it sustains economic viability” |
| PEFC | “Environmentally appropriate, socially beneficial, and economically viable management of forests for present and future generations” |
| European Commission | “Natural sustainable ecosystems provide the biological basis of forest biodiversity, its functions, and growth cycles. When forest biodiversity is based on man's intervention, it is called sustainable forest management.” |

| | |
|---|---|
| FAO | "Sustainable forest management addresses forest degradation and deforestation while increasing direct benefits to people and the environment. At the social level, sustainable forest management contributes to livelihoods, income generation and employment. At the environmental level, it contributes to important services such as carbon sequestration and water, soil and biodiversity conservation." |

## 2.3 Forest carbon

The following terms are often used relating to forest carbon and thus it is important to understand them.

**Table 4: Forest carbon definitions**

| *Term* | *Definition* |
|---|---|
| Above-ground carbon | "Carbon in all living biomass above the soil, including stem, stump, branches, bark, seeds, and foliage"[6] |
| Below-ground carbon | "Carbon in all biomass of live roots. Fine roots of less than 2 mm diameter are excluded, because these often cannot be distinguished empirically from soil organic matter or litter"[6] |
| Carbon sink | "Any process, activity or mechanism that removes carbon from the atmosphere"[10] |
| Carbon stock | "The absolute quantity of carbon held within a pool at a specified time. The units of measurement are mass."[2] |
| Carbon sequestration | "The uptake (i.e., the addition of a substance of concern to a reservoir) of carbon containing substances, in particular carbon dioxide ($CO_2$), in terrestrial or marine reservoirs."[10] |
| Carbon pool | "A reservoir of carbon. A system which has the capacity to accumulate or release carbon."[2] |
| Carbon flux | "Transfer of carbon from one carbon pool to another in units of measurement of mass per unit area and time (e.g., t C ha -1 yr-1)"[2] |
| Forest carbon | All carbon pools associated with forest ecosystem, classically 5 main categories: Above-ground carbon, below-ground carbon, dead organic matter (DOM) in wood, DOM in litter, and soil organic matter (*Based on Watson*[11]) |

[10] IPCC, 2014, **Climate Change 2014: Synthesis Report**

[11] Watson, 2009, **Forest Carbon Accounting: Overview & Principles**, *United Nations Development Programme*

# 3. THE IMPACT OF SFM ON FOREST CARBON STOCK

## 3.1 How interventions may increase productivity

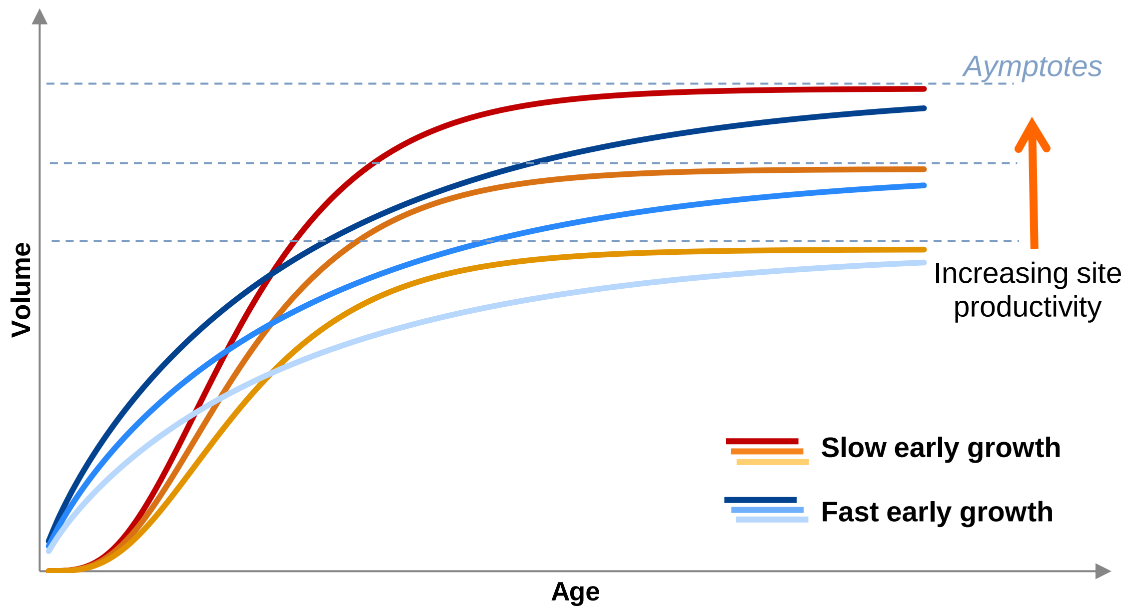
### *3.1.1 Forest growth overview*

Trees grow increasing their volume and sequestering carbon through the processes of photosynthesis and respiration. These processes are functions of climatic and physiological conditions such as light, moisture, temperature, $CO_2$ concentration, and soil nutrient levels.

The growth of most tree species is generally observed to have a S-shaped growth curve with initially slow growth followed by a period of higher growth before reaching a period of slowing growth towards an asymptote (maximum) volume (Figure 1). The initial slow growth may be short (for example in more shade tolerant species) and the s-shape may not be observed which results in growth curves as shown in blue in Figure 1.

The presence of an asymptote in individual tree growth is widely acknowledged. While the physiological cause has not been attributed to any one factor (and is beyond the scope of this report), constraints on how much water can be moved around large trees for photosynthesis is also likely to have some role[12]. Thus the asymptote will vary based on the site and climatic conditions, with more favourable sites for productivity having higher asymptotes.

**Figure 1: Tree growth variation due to site productivity in common growth forms**




The growth trends in Figure 1 will also be seen at the stand level, with stands will reaching an upper limit of biomass a site can support above which trees will begin to die through

[12] Ryan *et al.*, 2006, **The hydraulic limitation hypothesis revisited**, *Plant, Cell and Environment **29***

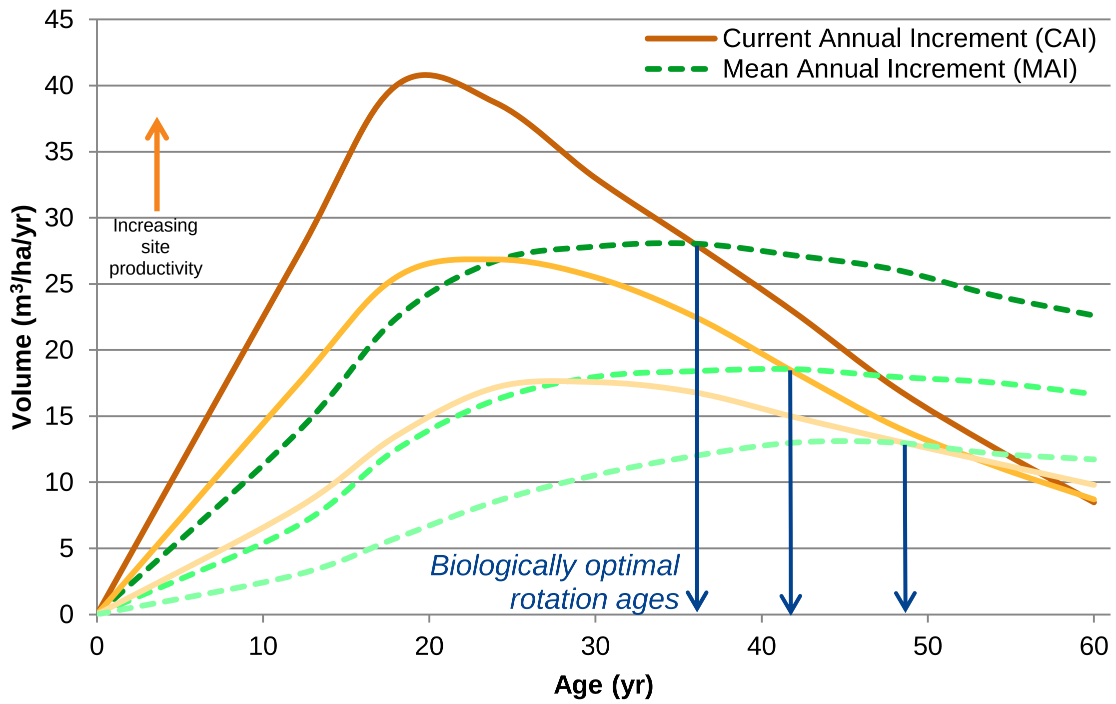
self-thinning[13]. Further to this, at stand level it is even possible for volume to even drop in time due to increases in mortality associated with natural disturbance events that become more likely the older a stand becomes.

Increment is often referred to in forestry and represents the change in volume over a given time. The two most commonly used increments in forestry are:

- *Current annual increment* (CAI): the volume accumulated in any given year of growth;
- *Mean annual increment* (MAI): the mean volume accumulated per year over all years of growth

Stands on more productive sites (or with higher productivity species) will reach a higher current and mean annual increment, compared to lower productivity sites. However these high productivity stands will reach this point sooner than the lower productivity stands (Figure 2). The maximum MAI occurs when the CAI intersects with the MAI (once the current annual increment is below the MAI it begins to reduce the MAI). The age when this occurs is referred to as the optimal biological rotation age, as if stands are grown with a rotation equal to this age biological volume production is maximised over its lifetime. Sites with higher productivity will have shorter biologically optimal rotation lengths. It should be noted that biologically optimal rotations are not always aligned with economically optimal rotation lengths.

**Figure 2: Example of biomass increment for Sitka spruce stands in the UK over a range of productivities**

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[13] Zeide, 1987, **Analysis of the 3/2 Power Law of Self-Thinning**, *Forest Science* ***33(2)***

The more productive sites see a greater relative fall in productivity after they reach the maximum increment versus to lower productivity site. All productivities eventually tend towards the point at which the current annual increment meets the x-axis: the age when the asymptote in volume is reached (Figure 2).

### 3.1.2 Enhancing growth

Growth can be enhanced throughout the rotation of a forest stand. During stand development, some of the factors impacting growth and increment can also be anthropogenically modified to increase forest growth. Soil nutrients and light can be modified through cultivation and fertilisation; and understory management and thinnings can reduce competition and increase light availability. Such actions are typically referred to silvicultural activities. Even prior to and during establishment, management can begin to impact growth through selecting improved genetic material and choosing where species are most suited to maximise growth. In addition to this other anthropogenic factors may impact forest growth such as climate change. If forest growth is increased more carbon from the atmosphere can be sequestered in the forest over a given time. These activities are discussed in more detail in the following sections.

#### 3.1.2.1 Fertilisation

Fertilisation involves the application of nutrients which are lacking or are reduced in certain soils, but are required for photosynthesis: nitrogen, phosphate, and potassium are typical nutrients.

Fertilisation effect has been studies in a variety of forests around the world: for example in loblolly pine plantations in the US South[14], semi-natural Douglas fir in the Pacific Northwest[15], Sitka spruce plantations in the UK[16], and even in species-rich natural lowland tropical forests around the world[17]. In all cases it has shown that fertilisation can increase growth, though the impact is dependent on site factors.

Generally, it is the case that the greatest impact is when fertiliser applications are made in younger stands though the impact of fertilisation is usually experienced over the whole rotation. Studies of loblolly pine in the US South have shown that fertilisation in the earlier years of a rotation can result in average increases in yield of 87 $m^3$/ha over the course of a 25 year rotation[18]. Although early fertilisation is the usual approach, some positive impact on growth of fertilisation in older stands has also been reported[15].

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[14] Sampson *et al.*, 2006, **Fertilization effects on forest carbon storage and exchange, and net primary production: A new hybrid process model for stand management**, *Forest Ecology and Management **221(1-3)***

[15] Dou *et al.*, 2015, **Impact of Nitrogen Fertilization on Forest Carbon Sequestration and Water Loss in a Chronosequence of Three Douglas-Fir Stands in the Pacific Northwest**, *Forests **6***

[16] Nair *et al.***,** 2016, **Does canopy nitrogen uptake enhance carbon sequestration by trees?**, *Global Change Biology **22***

[17] Wright *et al.***,** 2018, **Plant responses to fertilization experiments in lowland, species-rich, tropical forests**, *Ecology, to be published*

[18] Fox *et al.*, 2007, **Tree nutrition and forest fertilization of pine plantations in the Souther United States**, *Southern Journal of Applied Forestry **31(1)***

#### 3.1.2.2 Understory management

Understory management aims to reduce the competition of other plants that are growing in the forest with crop trees (weeds, or undesired tree species). This can be conducted in a number of ways: manually or mechanically removing the understory, or application of herbicides to chemically remove understory. Management of the understory is particularly important in younger stands where even small weeds may compete with sapling trees for water, nutrients and light, and thus weed control has been suggested as a cost effective way to increase carbon storage in forests[19].

Positive impact of understory management on growth and increment has been shown in eucalyptus plantations in China[20], semi-natural Scots pine forests in Switzerland[21], and a long term study of semi-natural ponderosa pine in Oregon found that removal of understory vegetation increased the speed at which the tree canopy area developed[22], which has the potential to further accelerate growth.

Other potential benefits of understory management include positive impact on fire risk as it reduces the potential fuel in the forest (see Section 3.1.3), and understory biomass removal has also been suggested as a possible energy source in the US South when converted to ethanol[23].

#### 3.1.2.3 Thinning

Thinning is the removal of a limited proportion of stems at some point prior to the final felling of a forest stand. These removed stems may be merchantable, although this is not always the case. If the wood is merchantable it may allow profit or at least offset thinning costs, further incentivising sustainable management. The main markets for thinned wood have traditionally been pulp producers though thinning material is increasingly being used by bioenergy producers in markets with diminished pulp production. Such bioenergy producers may even be able to take smaller dimensions of wood than pulp.

The aim of thinning is to reduce the competition between neighbouring trees for light, water, nutrients and growing space. The reduction in competition for the retained stems has been shown to increase growth per hectare for a wide range of forest types and tree species: examples include both coniferous and broadleaf species in semi-natural temperate forests[24], native tree reforestation in Costa Rica[25], and radiata pine in Australia and New Zealand[26].

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[19] Stokes & Willoughby, 2014, **Early weed control can increase long-term growth, yield and carbon sequestration of Sitka spruce stands in Britain**, *Forestry* ***87(3)***

[20] Zhou *et al.*, 2018, **Effects of understory management on trade-offs and synergies between biomass carbon stock, plant diversity and timber production in eucalyptus plantations**, *Forest Ecology and Management* ***410***

[21] Giuggiola *et al.*, 2018, **Competition for water in a xeric forest ecosystem – Effects of understory removal on soil micro-climate, growth and physiology of dominant Scots pine trees**, 2018, *Forest Ecology and Management* ***409***

[22] Oren *et al.*, 1987, **Twenty-four years of ponderosa pine growth in relation to canopy leaf area and understory competition**, *Forest Science* ***33(2)***

[23] Marinescu *et al.*, 2011, **Assessing forest understory biomass in northwest Florida (USA) and its potential to meet the state energy needs**, *Forestry Studies in China* ***13(4)***

[24] Juodvalkis *et al.*, 2005, **Effects of thinning on growth of six tree species in north-temperate forests of Lithuania,** *European Journal of Forest Research* ***124(3)***

The intensity of thinning may be important in determining a positive impact on overall stand growth, with simulations showing that too intense thinnings may reduce overall productivity in stands and thus carbon sequestration[27]. The thinned volume may not be replaced by growth of the remaining stems, and intense thinnings may also temporarily reduce whole stand productivity as the trees are not able to take full advantage of the nutrients, water and light available within the stand until the canopy closes again[28].

Similar to understory vegetation thinning can also have a positive impact on fire management if conducted in certain ways (see Section 3.1.3).

#### *3.1.2.4 Establishment enhancements*

Prior to even placing any trees in the ground, sustainable forest management can begin to improve future productivity. Ensuring the correct species is planted for given sites ensures not only that growth will be optimal, but that a species will be able to survive. Decision support tools have been developed for this around the world. Examples include tools for temperate forests in the UK[29] and Ireland[30], or for fast growing exotic species plantations in South Africa[31].

In addition to understanding what species should be planted where, it is also important to consider where the genetic material will come from. Certain provenances of seeds or seedlings may be better suited than others, especially in a changing climate. For example, in British Columbia, Canadian foresters have been moving seeds from lower elevation seed sources to higher elevation to counteract the warming climate and allow species to continue to grow[32]. In addition to this tree breeding programs continue to work to enhance the genetic material available to forest managers. For example tree breeding programs in Finland and Sweden have seen genetic growth gains of between 10-25% over unimproved seed stock[33]. Clonal material can also be used to provide proven growth traits in genetic material, though it is important to take action to reduce risks to reduced genetic diversity when applied[34].

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[25] Redondo-Brenes, 2007, **Growth, carbon sequestration, and management of native tree plantations in humid regions of Costa Rica**, *New Forests* ***34(3)***

[26] Sheriff, 1996, **Responses of carbon gain and growth of *Pinus radiate* stands to thinning and fertilizing**, *Tree Physiology* ***16***

[27] Alam *et al.*, 2008, **Impacts of thinning on growth, timber production and carbon stocks in Finland under changing climate**, *Scandinavian Journal of Forest Research* ***23(6)***

[28] Garcia, 2013, **Forest Sands as Dynamical Systems: An Introduction,** *Modern Applied Science* ***7***

[29] Forest Research, **Ecological Site Classification Decision Support System**, *accessible at: https://www.forestresearch.gov.uk/tools-and-resources/forest-planning-and-management-services/ecological-site-classification-decision-support-system-esc-dss/*

[30] Coford, 2003, **A guide to forest tree species selection and silviculture in Ireland**

[31] Louw & Scholes, 2002, **Forest site classification and evaluation: a South African perspective**, *Forest Ecology and Management* ***171(1-2)***

[32] Marris, 2009, **Forestry: Planting the forest of the future**, *Nature* ***459***

[33] Jansson *et al.*,2017, **The genetic and economic gains from forest tree beeding programmes in Scandinavia and Finland**, *Scandinavian Journal of Forest Research* ***32(4)***

[34] Burdon & Aimers, 2003, **Risk management for clonal forestry with Pinus radiate – Analysis and review. 1: Stragic issues and risk spread**, *New Zealand Journal of Forestry Science* ***33(2)***

During establishment, forest management can further increase survival and growth versus unmanaged stands. Intensive ground preparation can cause significant improvement to long term growth, causing improvements to soil temperature and improving root growth and the uptake of water and nutrients[35]. This was shown in the US South where high intensity ground preparation led to approximately 40% gains in growth over low intensity ground preparation[36]. However, this may not always be the case, with an example in central Europe indicating that ground preparation had no discernible impact on growth[37]. Thus growth gains are likely be dependent on local soil conditions.

In some geographies susceptible to annual periods of drought, management at establishment can be vital ensure growth by avoiding planting before dry seasons to reduce mortality in seedlings. Alternatively resilience to drought can be provided by planting seedlings with water retaining agents (hydrogels)[38], effectively increasing the growing season for such areas.

Active management of establishment will also ensure that the optimal planting density is achieved to maximise growth, and will usually include a course of beating up (or blanking) to replace plantings which have failed within the first year to ensure optimal density is achieved.

#### *3.1.2.5 Large scale change impacting growth*

While temperature, rainfall, and $CO_2$ concentration are not easily manipulated, it is important to note that globally changes are occurring: $CO_2$ concentration is increasing with burning of fossil fuels; and climate is also changing (increasing temperatures, longer growing seasons, changes in precipitation). This has the potential to both positively and negatively impact forest growth.

Studies have shown measurements of biomass accumulation exceed expected growth in line with atmospheric $CO_2$ and temperature increases both in mixed natural hardwood stands in the US South[39,] and plantation forests in Japan[40]. Simulation studies using models that attempt to replicate the physiological processes of forest growth have also shown that the changes in climate and atmosphere may increase growth especially in colder areas[41], although this is not universally the case with some studies simulating

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[35] Forestry Commission, 2009, **Improved Conifer Timber Quality Guidance Note: Establishment Practice**

[36] Nilsson & Allen, 2003, **Short- and long-term effects of site preparation, fertilization and vegetation control on growth and stand development of planted loblolly pine**, *Forest Ecology and Management* ***175***

[37] Aleksandrowicz-Trzcinska *et al.*, 2017, **Effects of reforestation and site preparation methods on early growth and survival of Scots pine in South-Eastern Poland**, *Forests* ***8***

[38] Viero *et al.*, 2000, **The effect of a soil-amended hydrogel on the establishment of a Eucalyptus grandis x E. camaldulensis clone grown on the sandy soils of Zululand**, *South African Forestry Journal* ***188(1)***

[39] McMahon *et al.*, 2010, **Evidence for a recent increase in forest growth**, *Proceedings of the National Academy of Sciences of the USA* ***107(8)***

[40] Fang *et al.*, 2014, **Evidence for environmentally enhanced forest growth**, *Proceedings of the National Academy of Sciences of the USA* ***111(26)***

[41] Kinderman *et al.*, 2013, **Potential stocks and increments of woody biomass in the EU under different management and climate scenarios**, *Carbon Balance and Management* ***8(3)***

growth finding no net impact on growth (e.g. in boreal Canada[42]). Climate change has also been modelled to have negative impacts such as increased mortality (or at least reduced growth) due to drought[43] or increased catastrophic damage risks (fire, wind, insect)[44] which can also cause mortality and reduce growth.

It may be the case that the silvicultural activities detailed above need to be used in order that growth can be prevented from falling under the pressures of changing climatic and atmospheric conditions. The lack of net impact of increased $CO_2$ levels on forests mentioned above could be a result of nutrient limitation which can restrict growth. This was shown in a study in North Carolina pine forests[45], where productivity increases were only observed when $CO_2$ enrichment was coupled with fertilisation. The impact of thinning and understory management on fire risk is discussed further in the next section.

### 3.1.3 Natural disturbance related interventions

Forests can be damaged or lost due to natural disturbances such as fire, wind, and pests and diseases. This impacts large areas of forest each year, for example, in the US an average of 680,183 hectares burn each year[46], and in Canada an even higher 2.1 million hectares burn each year[47]. In the European Union it is reported that approximately 6% of forested land (some 10 million hectares) is damaged by natural disturbances each year[48]

Forests may have been put at higher risk for such damages by historic management practices, which have focused more on timber production. A good example of this is Canada, where through the mid-20th century forest management was focused on fire suppression, attempting to extinguish all fires to prevent loss to wood (and other property), however this resulted in strong recovery of the undergrowth allowing fires to jump from understory to canopy increasing fuel and fire intensity. More recently however, fire has been recognised as a natural forest process by forest managers and management involves attempts to reduce fuel loads through controlled fires[49]. As mentioned in the previous section, anthropogenic climate change is also increasing the risk of natural disturbance.

Sustainable forest management to counteract these increased risks, and mitigate impacts where damage has happened is therefore often appropriate.

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[42] Girardin *et al.*, 2016, **No growth stimulation of Canada's boreal forest under half-century of combined warming and CO2 fertilization**, *Proceedings of the National Academy of Sciences of the USA* ***113(52)***

[43] Allen *et al.*, 2010, **A global overview of drough and heat-induced tree mortality reveals emerging climate change risks for forests**, *Forest Ecology and Management* ***259(4)***

[44] Dale *et al.*, 2001, **Climate Change and Forest Disturbances**, *BioScience* ***51(9)***

[45] Oren *et al.*, 2001, **Soil fertility limits carboin sequestration by forest ecosystems in a $CO_2$- enriched atmosphere**, *Nature* ***411***

[46] US National Interagency Fire Center, 2018, **Daily Report**, *available at: https://www.nifc.gov/fireInfo/nfn.htm*

[47] **Canadian National Fire Database**, *available at: http://cwfis.cfs.nrcan.gc.ca/ha/nfdb*

[48] European Union, **The European Union and forests**, *available at: http://www.europarl.europa.eu/atyourservice/en/displayFtu.html?ftuId=FTU_3.2.11.html*

[49] Hirsch, 2004, **Feature Article – Forest Fires and Sustainable Forest Management in Canada**, *Policy Horizons Canada: Sustainabe Development Where Next?* ***Govt. of Canada***

#### *3.1.3.1 Preventative management*

Sustainable forest management can help avoid these natural disturbances and losses to growth, maintaining forests as active carbon sinks:

- Wind damage can be minimised by ensuring more wind resistant species are placed in higher wind risk areas, thinning less (or earlier), and in taking care to manage fellings to leave wind-firm edges[50]
- Increasing or maintaining species diversity to forest stands can reduce the impact of pests and diseases[51,52]
- Removing understory vegetation either manually or through preventative, controlled (low intensity) burns reduces the amount of fuel in forests which can lead to intense and destructive fires. This will of course release some carbon, though depending on the intensity of the intervention this may be resequestered by the forest in time[53]. Consideration of this should be made in planning. Retention of mid-sized trees is suggested as a good method of maintaining growth and productivity in the stand.
- Thinning may also help to reduce fire damage, although this is dependent on the type of thinning. The best type of thinning for reducing crown fire is one which removes the smaller stems from a forest, thus increasing the canopy base height and reducing the likelihood of catastrophic fire[54].

#### *3.1.3.2 Post damage actions*

Where forests are being actively managed, the impact of disturbance events can potentially be reduced, and forests can transition from the damage to being productive more quickly. Disturbed forests have been found to transition from a carbon source (net emitter) to a sink more quickly when management follows disturbance with a salvage harvest versus leaving wood in the forest[55] and a study in the US South found actively managed forests recovering (and thus showing higher productivity and sequestration) more rapidly than unmanaged forests following wind damage[56].

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[50] Quine *et al.*, 1995, **Forests and Wind: Management to Minimise Damage**, *Forestry Commission Belletin 114*

[51] **NF5 Planted forest tree species diversity index**, available at: https://www.climatexchange.org.uk/research/indicators-and-trends/indicators/nf5-planted-forest-tree-species-diversity-index/

[52] Guyot *et al.*, 2015, **Tree Diversity Limits the Impact of an Invasive Forest Pest**

[53] Weichmann *et al.*, 2015, **The carbon balance of reducing wildfire risk and restoring process: an analysis of 10-year post-treatment carbon dynamics in a mixed –conifer forest**, *Climatic Change **132(4)***

[54] Peterson *et al.*, 2003, **Fuels planning: Managing forest structure to reduce fire hazard**, *Second International Wildland Fire Ecology and Fire Management Congress and Fifth Symposium on Fire and Forest Meteorology*

[55] Yamanoi *et al.*, 2015, **Effects of a windthrow disturbance on the carbon balance of a broadleaf deciduous forest in Hokkaido, Japan**, *Biogeosciences **12***

[56] Laing *et al.*, 2011, **How management strategies have affected Atlantic White-cedar forest recovery after massive wind damage in the Great Dismal Swamp,** *Forest Ecology and Management **262***

Damaged forests under active management also have the potential to have the damaged wood salvaged, preventing the carbon stored in the wood from simply being released back into the atmosphere. It can instead go to storage in products or use as bioenergy to offset fossil fuel emmissions.

In addition to this, observing damages in forests which may not have been established with sustainable principles can help to lead to future practices which are more sustainable, identifying what risks forests are subject to[57].

## 3.2 Potential negatives of forest management and how to minimise such effects

Balancing objectives is key to sustainable forest management, and the current and future impact of a management decision should always be considered. It is clear that a one-approach fits all forest management (as may have been historically applied) is no longer responsible or sustainable. It is important to note that both regulations and voluntary schemes such as certification by FSC or PEFC are encouraging forest managers to move away from forest management which can cause negative impacts.

### 3.2.1 Silviculture and forest structure

Silvicultural practices, especially when concerned with the use of chemicals are raised as potential negative aspects of forest management. Studies are not definitive in regard to the impacts of herbicides such as the widely used glyphosate, with some reports pointing to observations of negative impacts[58], although more recent studies indicate that it does not pose a significant risk to humans or environment when used in an appropriate manner in the forest environment[59]. Generally however, sustainable forest management is aiming to reduce the use of pesticides[60] and herbicides and instead favouring other substitute options such as research based applications of biological control. Likewise fertiliser application can also easily lead to moving away from ecological objectives in pursuit of productive optimums[61], and care must be taken to take this into account in sustainable forest management.

In terms of carbon, studies which have considered the emissions associated with silvicultural practices have found that the gains in growth and carbon storage in soil, pulp and sawnwood products outweigh the emissions[62] and do not lead to large increases in carbon payback time[63]. However, the emissions will depend on the silvicultural operations undertaken, and even seemingly similar operations in Sweden and Finland were shown to

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[57] Wiersum, 1995, **200 years of sustainability in forestry: Lessons from history**, *Environmental Management* ***19(3)***

[58] Buffin *et al.* 2001, **Health and environmental impacts of glyphosphate: the implications of increased use of glyphosphate in associateion with generticallly modified crops**, *Prepared for Friends of the Earth*

[59] Rolando *et al.*, 2017, **The risks associated with glyphosate-based herbicide use in planted forests**, *Forests* ***8, 208***

[60] Forestry Commission, 2004, **Reducing Pesticide Use in Forestry**, *HMSO UK*

[61] Good & Beatty, 2011, **Fertilizing Nature: A Tragedy of Excess in the Commons,** *PLOS Biology* ***9(8)***

[62] Markewitz, 2006, **Fossil fuel carbon emissions from silviculure: Impacts on net carbon sequestration in forests**, *Forest Ecology and Management* ***236(2-3)***

[63] Jonker *et al.*, 2013, **Carbon payback period and carbon offset parity point of wood pellet production in the South-eastern United States**, *Global Change Biology Bioenergy* ***6(4)***

have differing silvicultural carbon emissions (mostly based on differences in draining of soils)[64]. Consideration in terms of carbon consequences versus gains in growth should be made by forest managers when deciding upon silvicultural operations, and as more data becomes available, decision support tools are becoming more available for use in this field.

Plantation monocultures are often pointed to as a negative aspect of intensive forest management. There are a couple of issues that are of concern with monocultures: as previously mentioned, lack of species diversity can lead to increased susceptibility to pests and disease. Monocultures are also criticised for the use of exotic species such as Sitka spruce in the UK or Eucalyptus in Uruguay, and the consequent lack of biodiversity they support. While studies have concluded that movement away from monocultures can potentially lead to biodiversity gains[65], there is also evidence that plantations can provide valuable habitat or act as a link between separated natural forest[66]. Indeed studies in the UK have shown both positive and negative impacts of the introduction of Sitka on biodiversity, with lower vascular plant diversity than native stands but richer diversity of fungal and invertebrate communities[67]. Thus studies have concluded that there is not a simple answer as to whether plantations (including exotic species) are bad for biodiversity[68]. Nonetheless, in order to manage plantations sustainably, efforts should be made by managers to consider adjustments to improve biodiversity. In many cases sustainable plantation management is already taking into account the wider landscape, even enhancing biodiversity by providing for protection of sensitive sites and creating wildlife corridors between areas of natural. Even without increasing species diversity: It has been suggested that even small adjustments in management such as thinning earlier, increasing rotation length, or leaving areas of retention wood can increase biodiversity[69].

The use of monocultures may also have an impact on growth and carbon storage, with some evidence that mixed stands have the same or greater growth than monocultures[70]. This and the potential reduced resilience of monocultures mean that consideration is necessary as to whether monocultures continue to be sustainable. In many cases already, there is a movement away from monocultures with management trending toward planting a diversity of species, because it is suggested as best practice, or required for certification or by law to gain harvesting licences[76].

Initiatives such as the New Generations Plantation (NGP) platform started by WWF in 2007[71] represent good examples of how plantations can address these concerns. The

[64] Berg & Karjalainen, 2003, **Comparisons of greenhouse gas emissions from forest operations in Finland and Sweden**, *Forestry* ***76(3)***

[65] Felton *et al.*, 2010, **Replacing coniferous monocultures with mixed-species production stands: An assessment of the potential benefits for forest biodiversity in northern Europe,** *Forest Ecology and Management* ***260(6)***

[66] Brokerhoff *et al.*, 2008, **Plantation forests and biodiversity: oxymoron or opportunity?**, *Biodiversity and Conservation* ***17(5)***

[67] Humphrey *et al.*, 2009, **The potential contribution of conifer plantations to the UK Biodiversity Action Plan**, *Botanical Journal of Scotland* ***54(1)***

[68] Parotta *et al.*, 2006, **Planted forests and biodiversity**, *Journal of Forestry* ***104(2)***

[69] Hartley, 2002, **Rationale and methods for conserving biodiversity in planation forests**, *Forest Ecology and Management* ***155(1-3)***

[70] Hulvey *et al.*, 2013, **Benefits of tree mixes in carbon plantings**, *Nature Climate Change* ***3***

[71] WWF, **New Generation Plantations**, available at: *www.newgenerationplanations.org*

NGP includes many participant plantations globally, all with sustainable forest management based on four key principles:

- Maintain ecosystem integrity
- Protect and enhance high conservation values
- Be developed through effective stakeholder involvement processes
- Contribute to economic growth and employment

### 3.2.2 Harvesting practices

Harvesting and thinning will usually require the use of machinery, which is the safest and most efficient approach for felling trees. However, using heavy machinery can lead to negative consequences in forest soils, such as compaction increasing runoff and erosion[72]. Additionally machinery will release carbon emissions when operating, and can further release carbon through soil disturbance. Using appropriately sized machines equipped with the suitable wheels can help to reduce the disturbance. Additional on-site actions are also undertaken in sustainable forest management to reduce harvesting impact. These include using and maintaining brash mats to reduce machinery rutting and disturbing soil[73], carefully planning harvesting and extraction routes based on underlying topography, and management of on-site water through maintenance and establishment of drains and watercourse crossings by installing pipes or culverts[74], and installing sedimentation controls such as silt fences[75]. In many cases consideration and action to avert damage is now required by national forest standards in order to gain harvest licences (e.g. UK[76]).

Another criticism can be that harvesting is too intense, and more wood is harvested than is allowed to regrow, potentially reducing the overall carbon store. While this should not occur in sustainably managed forests there are instances where in a given year the volume removed may exceed growth: storm damage in a year could require salvaging bringing more volume out of the forest than was anticipated, thus requiring reductions in future years or conversely, weather conditions may reduce harvest operations in one year, meaning that volumes may be adjusted upwards in the next year to ensure the sustainability of businesses reliant on receiving an adequate wood volume. By balancing over longer time periods the overall impact in terms of carbon can be balanced and sustainable. An example of this is the allowable annual cut setting in British Columbia

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[72] Cambi *et al.*, 2015, **The impact of heavy traffic on forest soils: A review**, *Forest Ecology and Management **338***

[73] Hutchings *et al.* 2006, **Soil compaction under timber harvesting machinery: a preliminary report on the role of brash mats in its prevention**, *Soil Use and Management **18(1)***

[74] The Forestry Commission, 2005, **Protecting the environment during mechanised harvesting operations**, *Technical Note*

[75] Ontario Woodlot Association, 2009, **A landowner's guide to careful logging**

[76] The Forestry Commission, 2017, **The UK Forestry Standard** available at: http://www.forestry.gov.uk/publications

which are typically set over a 10 year period[77], though can be adjusted by the chief forester as necessary to ensure sustainability.

## 3.3 Wider potential benefits of active forest management

Throughout the last sections it has been possible to see an indication that active, sustainable forest management can have benefits beyond simply increasing the productivity of forest stands. Here we provide further insight into what these benefits may be. Additional commentary with more specific examples is also provided in each of the case studies in Section 4.

### 3.3.1 Economic benefits

Managing forests for wood production leads to job and income creation: both directly in forest management and throughout the associated forest value chain. The World Bank states that the formal timber sector contributes 600 billion USD to the global economy, and is responsible for 54.2 million jobs: 13.2 million formally and 41 million informally[78].

In particular, forest management is of benefit to rural economies, which have recently struggled with aging populations and low employment rates[79]. Examples such as Sweden show how local economies have been enhanced by the presence of more active forest management[80], and conversely mill closures and reduced management in the US South have been shown to cause economic hardship[81] and results in migration away from rural areas.

Taxation can also be generated and help to foster further sustainable forest management, and allow for further environmental and social benefits such as outreach and protection of primary forests, although taxes must be carefully calibrated to be effective[82]. In the US South almost all States have some kind of severance tax for felled timber[83] with many ring-fencing income for local roads and schools.

### 3.3.2 Social benefits

In addition to job creation active forest management creates other social benefits. Sustainable forest management has been shown in Indonesia to have reduced firewood

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[77] Government of British Columbia, 2017, **Timber Supply Review Backgrounder,** https://www2.gov.bc.ca/gov/content/industry/forestry/managing-our-forest-resources/timber-supply-review-and-allowable-annual-cut

[78] The World Bank, 2016, **Forests Generate Jobs and Incomes**, *Brief available at: http://www.worldbank.org/en/topic/forests/brief/forests-generate-jobs-and-incomes*

[79] European Commission, 2017, **CAP Context Indicators 2014-2020,** *available at: https://ec.europa.eu/agriculture/cap-indicators/context/2017_en*

[80] Hillring, 2002, **Rural development and bioenergy-experiences from 20 years of development in Sweden**, *Biomass and Bioenergy* ***23(6)***

[81] Brandeis & guo, 2016, **Decline in the pulp and paper industry: effects on backward-linked forest industries and local economies**, *Forest Products Journal* ***66(1-2)***

[82] Karsenty, 2010, **Forest taxation regime for tropical forests: lessons from Central Africa**, *International Forestry Review* ***12(2)***

[83] National Conference of State Legislatures, **State Severance Taxes**, *available at: http://www.ncsl.org/research/fiscal-policy/2011-state-severance-tax-collections.aspx#KS*

dependence, respiratory infections and malnutrition[84] (partly through environmental benefits), and many certified plantations in the developing world have social development plans including education, healthcare and primary forest protection through engagement with local communities (e.g. Green Resources in East Africa[85], Miro Forestry in West Africa[86], and Proteak in Mexico[87]).

The recreational value of forests should be acknowledged and forest management can help facilitate recreational access through both creating more forest area near to populations or the development of roads and trails[88], and through the process of sustainable forest management areas with greater value for recreation might be identified and dedicated to this use rather than productive use[89].

### *3.3.3 Environmental benefits*

One of the main benefits of active forest management is that it can reduce pressure on primary or other forests with high environmental value. Many tropical hardwoods can be grown in plantations and such plantations have been mentioned as a way of meeting demand for tropical hardwoods without having to negatively impact natural forests[90]. Active forest management may even increase the protection of natural forests as communities may become more engaged with forest issues[91].

As has been previously mentioned, unmanaged forests are more prone to disturbances than managed forests. For example during a wildfire there is less dead and dying wood in a managed forest compared to unmanaged forests. Thus management can help stop fires reaching critical sizes and ending up a threat to life and property. In the event of a disturbance the carbon-release can be higher in unmanaged forests as the carbon storage can be higher than managed forests (see next section). A natural disturbance may release more carbon to the atmosphere than if the forest was harvested.[92]

Active forest management has also been stated by the FAO as a potential remedy to genetic erosion that is being seen in forests around the world[93]. Genetic erosion is the process by which the gene pools of species diminish because individuals fail to reproduce

[84] Miteva *et al.*, 2015, **Social and Environmental Impacts of Forest Management Certification in Indonesia,** *PLoS One* ***10(7)***

[85] Green Resources, 2017, **Directors' Report 2016/2017**

[86] Miro Forestry Company, 2016, **Annual Report**

[87] Proteak, 2016, **Annual Report**

[88] Cho *et al.*, 2014, **Effects of travel cost and participation in recreational activities on national forest visits**, *Forest Policy and Economics* ***40***

[89] Scarpa *et al.*, 2000, **Valuing the recreational benefits from the creation of nature reserves in Irish forests**, *Ecological Economics* ***33(2)***

[90] Varmola & Carle, 2002, **The importance of hardwood plantations in the tropics and sub-tropics**, *International Forestry Review* ***42(2)***

[91] The Forests Dialogue, 2018, **Key Lessons for Community Engagement in Forest Landscapes: Learning from 17 Years of TFD's Initiatives**

[92] Lippke *et al.*, 2001, **Life cycle impacts of forest management and wood utilization on carbon mitigation: knowns and unknowns,** *Carbon Management* **2:3**

[93] FAO, 2014, **The state of the World's forest genetic resources**

before they die. In turn by actively managing semi-natural forests and reducing genetic erosion can lead to genetic improvements in productivity.

## 3.4 Consequences of the absence of forest management

### 3.4.1 General consequences

The previous section detailed the wider benefits of active forest management, but it is also important to consider a situation in the absence of forest management. In addition to the obvious absence of the benefits discussed above there are potentially more impactful consequences. The absence of forest management also implies an absence of harvesting and hence absence (or at least reduction) of forest industry.

The absence of forest management is not likely to lead to an absence of forest harvesting: illegal logging is already widespread throughout the world in both developed and developing countries[94] and it would be unlikely that the absence of forest management (and hence associated forest value chain) would stop this occurring. As previously mentioned, forest management can remove the pressure of illegal logging in areas of primary forest, and can provide generally more oversight and engagement in the protection of primary forest resources[95].

A corollary of removing (or vastly reducing) forest products from the market is that other products must be used in their place. Construction is a major wood product consumer, and in the absence of wood, reliance would have to be more heavily placed on metals and concrete which have negative carbon impacts, and likewise having to revert to fossil fuels in the absence of the biomass created throughout the forest value chain would have negative impacts[96].

However, there are also potential benefits to the absence of forest management, with some studies indicating higher biodiversity in unmanaged forests[97,98].

On balance it is unlikely that such a drastic measure would be taken globally, but this illustrates that the absence of forest management in itself is not a sustainable proposition.

### 3.4.2 Carbon consequences in forest storage

In addition to the general consequences, it is important to understand the differences in carbon storage and sequestration rate between managed and unmanaged forests. It is of note that there is still much debate in the scientific literature concerning the differences, further confounded by a changing climate[99]. However, there are some general trends that are apparent concerning the differences and they are discussed here.

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[94] FAO, 2005, **Best practices for improving law compliance in the forest sector**

[95] Hansen & Trueue, 2008, **Assessing illegal logging in Ghana,** *International Forestry Review**10(4)***

[96] Oliver *et al.*, 2014, **Carbon, Fossil Fuel, and Biodiversity Mitigation with wood and forests**, *Journal of Sustainable Forestry **33***

[97] Paillet *et al.*, 2010, **Biodiversity differences between managed and unmanged forests: meta-analysis of species richness in Europe,** *Conservation Biology **24(1)***

[98] Brunet *et al.*, 2010, **Biodiversity in Europena beech forests – a review with recommendations for sustainable forest management**, *Ecological Bulletins **53***

[99] Bellassen & Luyssaert, 2014, **Carbon sequestration: Managing forests in uncertain times**, *Nature **506***

#### 3.4.2.1 Differences in carbon storage versus sequestration rate

The carbon storage and the sequestration rate are important factors to be considered. Carbon is constantly being released by anthropogenic activity such as burning fossil fuels, therefore it is desirable to be actively sequestering more carbon in forests through time. As forests grow they sequester carbon and store it in woody material.

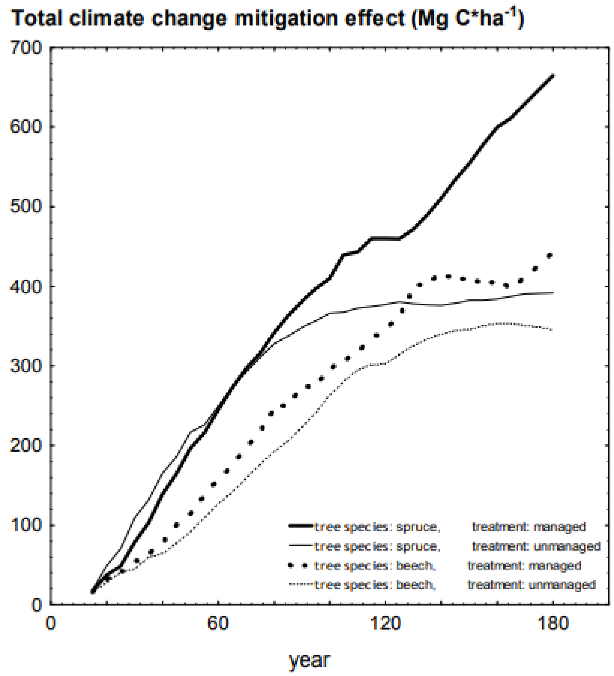
In the case of an unmanaged stand, sequestration will continue as the stand grows through time. However, as the volume in the unmanaged stand reaches the asymptote (as described in Section 3.1.1) while the stand will represent a large carbon store, the rate of sequestration will be balanced by respiration, mortality and decomposition in the stand causing a net sequestration of zero. It is even possible that an unmanaged stand may become a net carbon source if carbon emissions exceed sequestration.

This can be compared to a managed stand, which will be harvested at some point prior to reaching the asymptote in growth. The trees that are harvested can be converted to products which continue to store carbon, and the area that was harvested is replanted with new trees that will continue to sequester carbon.

This is illustrated in Figure 3: while carbon storage and sequestration rate from forest establishment are similar during the earlier stages of growth for both managed and unmanaged stands for both broadleaved species and conifers[100], in the long term managed forests are shown to sequester more carbon over a 180 year period. It is also important to note that while the unmanaged stand growth is tapering off in line with an asymptote, the managed forests have a sustained rate of carbon sequestration.

[100] Klein *et al.*, 2013, **The Contribution of Managed and Unmanaged Forests to Climate Change Mitigation—A Model Approach at Stand Level for the Main Tree Species in Bavaria,** *Forests* ***4***

**Figure 3: Total carbon storage in spruce and beech following planting in managed and unmanaged stands**




Source: Klein *et al.* (2013)

While this study considers the difference between unmanaged (or minimally managed) and managed stands at the stand level it is also important to understand what is happening at a larger forest or landscape scale. At the larger regional scale the impact of harvest removal in individual forest stands can be offset by the fact that harvest removals in sustainable management are usually below the average growth of an area. Other stands in the forest are left, continuing to grow and sequester carbon.

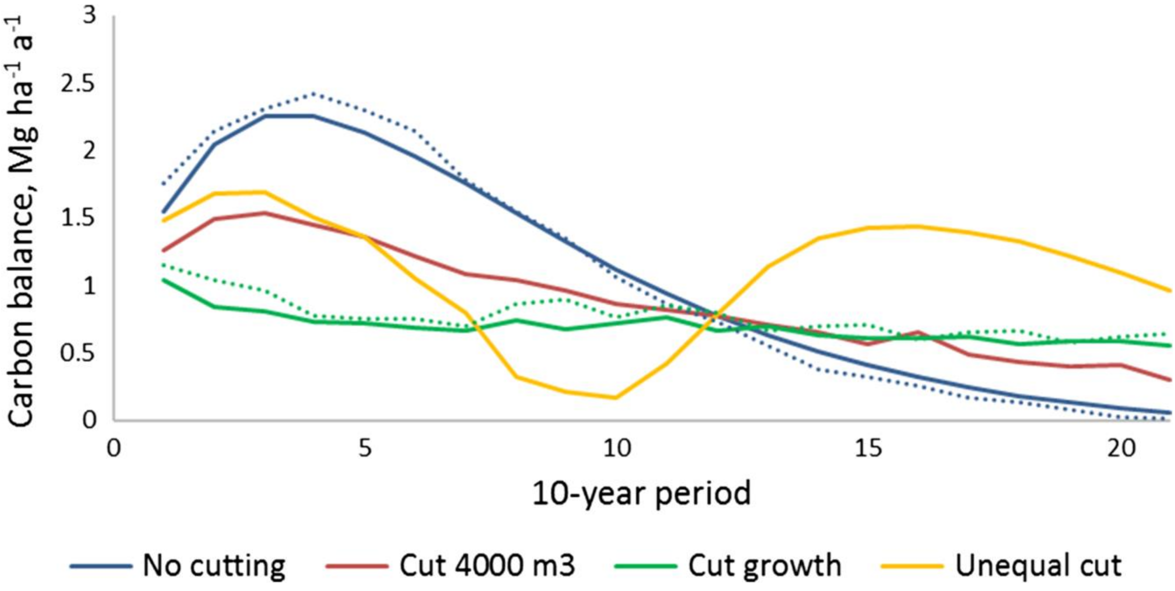
This was demonstrated by a simulation of the carbon balance (net difference between sequestration and emission of carbon) in a 147 ha Finnish forest consisting of pine, spruce and birch.  The study considered both in-forest and forest product carbon to demonstrate that the perceived carbon benefit of unmanaged forests is mostly a function of the length of time considered[101]. Four scenarios were considered:

1. Unmanaged, with no cutting (No cutting)
2. Harvesting 4000m$^3$ from the forest over each 10 year period, equivalent to a harvest of 50% of the volume increment over that period (Cut 4000 m$^3$)
3. Harvesting all of the volume increment from the forest in each 10 year period (Cut growth)
4. An uneven harvest level which initially increased and then decreased harvest until the end of the 12$^{th}$ 10 year period when harvesting ceases (Unequal cut)

[101] Pukkala, 2017, **Does management improve the carbon balance of forestry?**, *Forestry* ***90(1)***

Simulation of these scenarios can be seen in Figure 4, where the unmanaged stand represents the highest level of sequestration over 120 years, after which all other scenarios exceeded the carbon balance of the unmanaged stand. This is a result of the growth of the forecast stands in unmanaged forest reaching their asymptotes for growth, and a carbon balance of zero. Meanwhile, the scenarios with harvesting occurring are constantly experiencing replanting, which will sequester further carbon in growth. It is possible to see that because not all areas are lost at the forest scale due to harvesting that there are no great increases or drops in the carbon balance, because losses in harvested areas are offset by other areas in the forest which continue to grow and sequester carbon. Indeed, after approximately 170 years the more intense harvesting regime (Cut growth) even exceeds the carbon balance of the more conservative lower harvesting level.

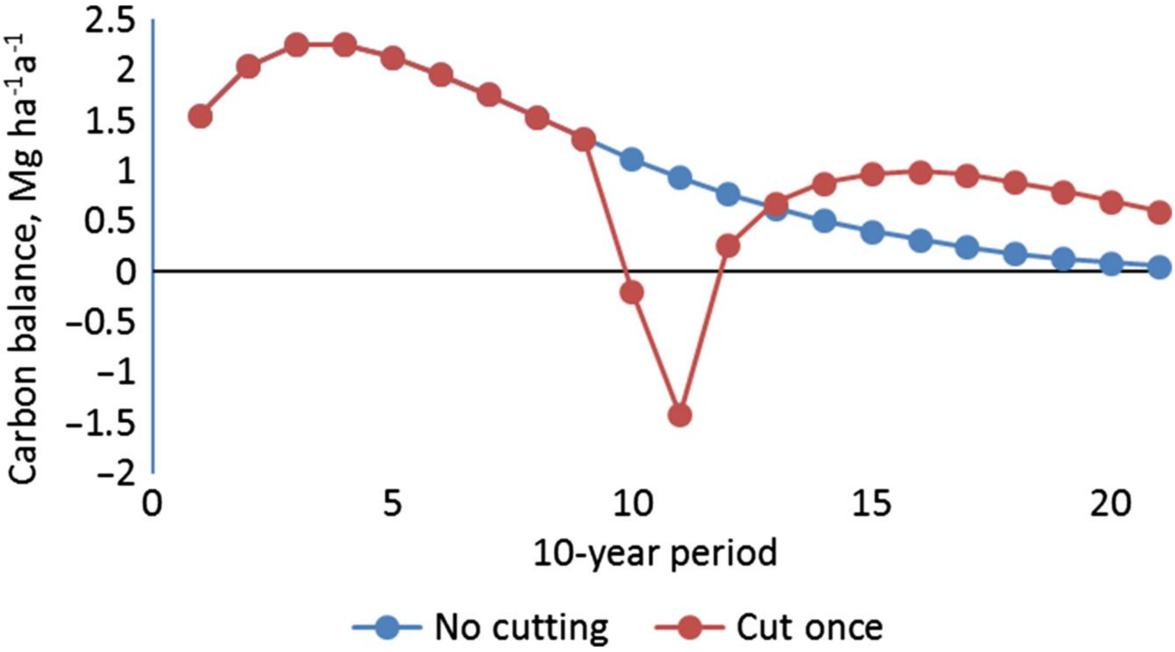
**Figure 4: Carbon balance of a typical Finnish forest under different management regimes over 200 years**




Source: Pukkala, 2017[101]

To demonstrate this further another scenario was forecast with only a single heavy harvest in 10th 10 year forecast period. While this led to a negative carbon balance (carbon was being emitted from the forest) for 30 years, it eventually reached a point where the carbon balance exceeded the unmanaged regime (Figure 5). This recovery in sequestration was achieved despite emissions from harvesting and the use of some of the extracted wood in short life products (e.g. pulp) or as bioenergy, because of the increased areas within the forest assumed to be replanted increasing the rate of carbon sequestration.

**Figure 5: Carbon balance of a typical Finnish forest with a single period of intense harvesting versus and unmanaged regime**




Source: Pukkala, 2017[101]

Another study at the regional scale considered all loblolly pine plantations in the US South[102]. Simulations of growth for 50 years under both unmanaged and managed scenarios showed that an unmanaged scenario achieved on average a cumulative carbon sequestration 40 tonnes/ha greater than simple forest management. However more intensive management scenario (including planting of genetically improved material, fertilisation and understory management) resulted in a combined storage in forest and products approaching the unmanaged scenario. Undoubtedly over a longer time period the intensively managed scenario would grow to exceed the unmanaged stands cumulative carbon sequestration.

Therefore while unmanaged (shut-the-gate) scenarios for forests may initially seem to provide a large carbon store, when considered over longer periods, at regional scales, it is apparent that sustainable forest management results in a greater level of carbon sequestration. The timescale over which this tipping point is reached is likely to be a function of species growth rates and management which increases growth rates can further reduce the time to exceed the sequestration of unmanaged stands.

It is clear that sustainable forest management should be favoured in active forests as a carbon-optimal approach to forestry[103], and that reforestation with managed forests provides greater carbon storage than unmanaged forests.

[102] Wang *et al.* 2010, **Long-term simulations of forest management impacts on carbon storage from loblolly pine plantations in the Southern U.S.**, *Joint Meeting of the Forest Inventory and Analysis (FIA) Symposium and the Southern Mensurationists*

[103] Krug *et al.*, 2012, **Revaluing unmanaged forests for climate change mitigation**, *Carbon Balance and Management **7(11)***

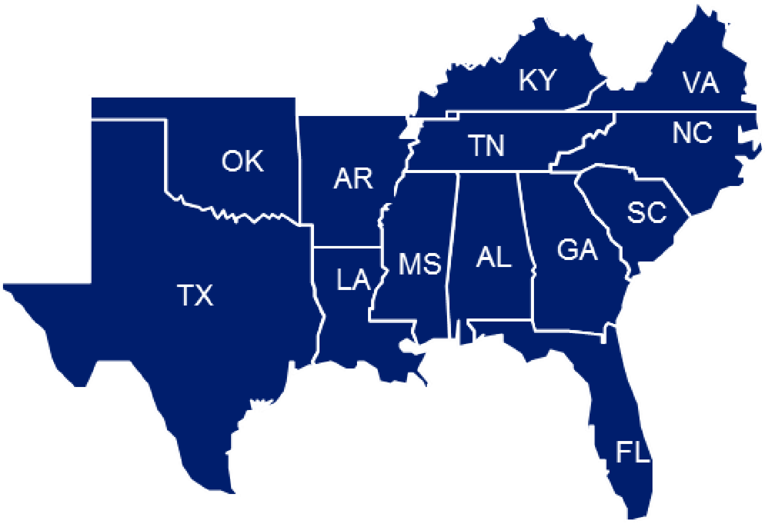
# 4. SFM CASE STUDIES

## 4.1 US South

The US South has been selected as a case study because it demonstrates how changing the forest management system of an existing forest area, from exploitatively harvesting areas of natural forest to more intensive management of plantations has increased above ground forest carbon stocks over historic levels with minimal change to forest area.

In this study US South is shown in Figure 6, as defined by the U.S. Forest Service including the 13 states: Alabama, Arkansas, North Carolina, South Carolina, Florida, Georgia, Kentucky, Louisiana, Mississippi, Oklahoma, Tennessee, Texas and Virginia.

**Figure 6: US South States**




### 4.1.1 *Forest Industry Overview*

The forest area in the US South comprises both hardwood and softwood areas which were historically managed by the indigenous population by the practice of large scale burning to create grazing for hunting ground. This process was repeated by the early European settlers who burnt large areas to create space for grazing and other agriculture. The forest industry in the US South dates back to the development of steam powered sawmills that were used by the Europeans settlers who harvested the best quality mature areas of forest and left those areas to naturally regenerate. However, forestry management practices in the region transitioned in the mid-20th century by becoming more intensive and focused on producing a sustainable supply of good quality timber. This was led by growing wood fibre demand in the regions that were developing wood processing industries (e.g pulpmills and wood based panel mills as well as more modern sawmills).

Over that transition the ownership of forestland in the US South has remained largely in private control: around 86% of the total forest land in the region is under private ownership (including 90% of the forestland designated as timberland; defined as forest land that is/capable of producing yield of at least 1.4 m³/ha/year ) of which 31% belongs to private corporations (which has been mostly converted to plantations) and 69% to individuals. The state owns around 14% within national forest or other public designations[104]. The private corporate ownership is split between integrated forest companies and institutional investors, the later who began acquiring timberland in the 1970s from forestry companies who were selling off forestland in order to raise capital to expand processing capacities. In more recent years institutional investors instead have favoured to invest via forest organisations call timberland investment management organisations (TIMOs) which hold and manage timberlands for investors. Forestry companies that did not wish to completely divest have also largely moved to holding their forestland in Real Estate Investment Trusts (REITs) which have tax advantages. REITs may be publicly traded and provide another avenue for institutional investment in forestland.

The timber utilising industry in the US South is now significant and the main consuming industry of wood fibre is that of pulp, followed by sawmills, wood based panel mills, pellet mills and bioenergy. Pulpmills and pellet mills produce goods mainly for the export market whilst sawmills are largely driven by domestic demand from the construction sector, with softwood sawnwood used for timber framing and hardwood sawnwood for interior surfaces and furniture.

### *4.1.2 Forestry development*

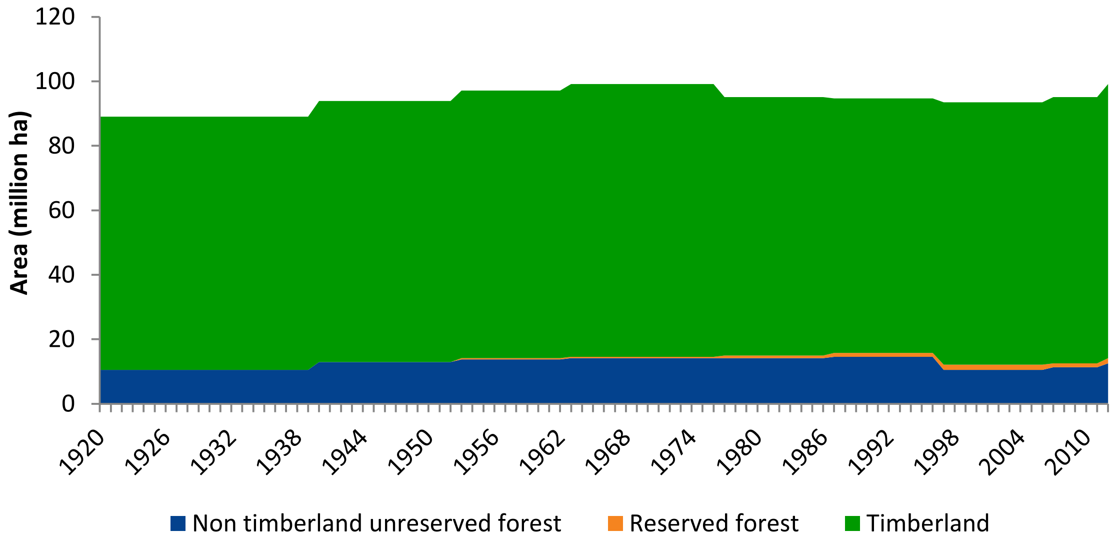
#### *4.1.2.1 Total forest area*

Since the 1920's the total reported area of forest land has been reasonably stable (Figure 7), fluctuating between 89 – 99 million ha between assessments. In 2015 around two thirds (64%) of the forest area was hardwood forest and around one third (34%) was softwood. The proportion of timberland has also been stable, at around 86% of the total forest area between 1920 and 2012. Since the 1950s the proportion of reserved timberland has increased to around 2% of the total forest area by 2012, this area is protected from timber harvesting[105].

[104] Wear, 2014, **Forest Managemnet and Timber Production in the US South,** *Working paper of the Southeastern Centre for Forest Economics Reseach*

[105] Oswalt & Smith, 2014, **US Forest Resource Facts and Historical Trends,** *US Department of Agriculture, Forest Service*

**Figure 7: US South Forest area 1920-2012**

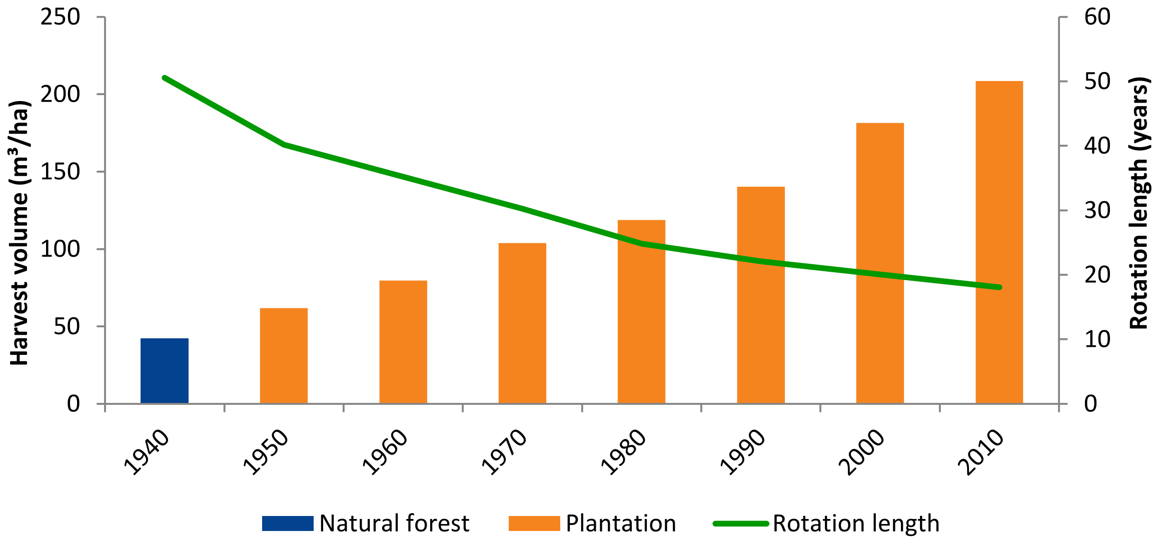



### *4.1.2.2 Yield*

As more intensive management has been increasing in the US South, the yield of wood fibre from forests has also increased. For example, the average maximum mean annual increment of softwood plantations has increased by around 14 times by 2010 compared with that of natural forest rotations harvested in the 1940s[106].

[106] Fox *et al.*, 2004, **The evolution of pine plantation silviculture in the Southern United States,** *US Department of Agriculture, Forest Service, Southern Research Station*

**Figure 8: US South average harvest volume and rotation length 1940-2010**

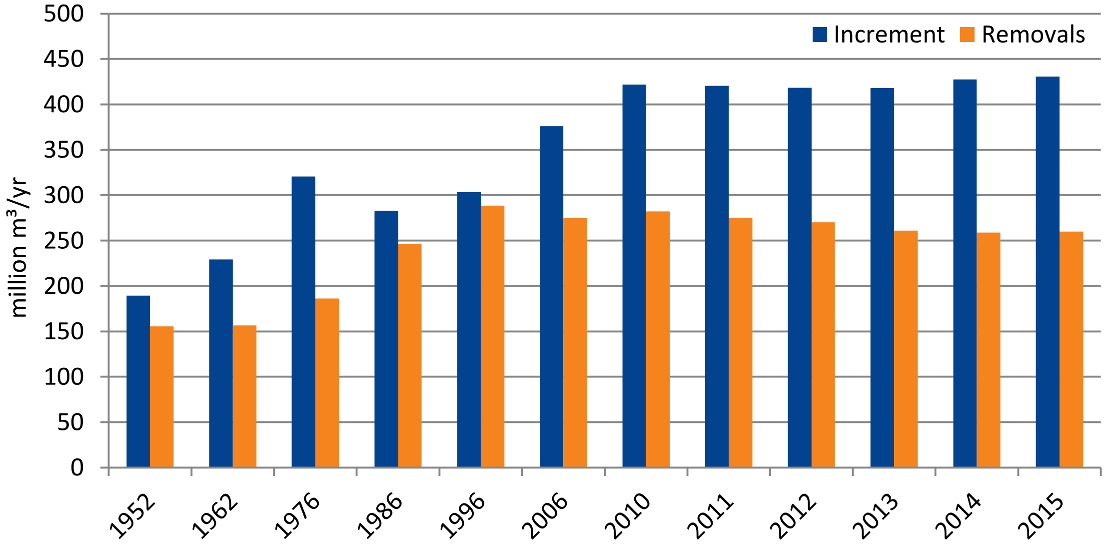



Note: data for 1940 is harvesting a natural forest on a 50 year rotation which has since been replaced by increasingly productive plantations as the source of harvested timber.

### *4.1.2.3 Growth to removal ratio*

Despite the development of the forest industry in the region, inventories since 1952 show that total growth has always exceeded the rate of removals despite increasing demand from industries. In recent years since 2010 there has been more than 50% more growth in the forest than the volume removed through harvesting activities[105].

**Figure 9: US South historical increment to removal**



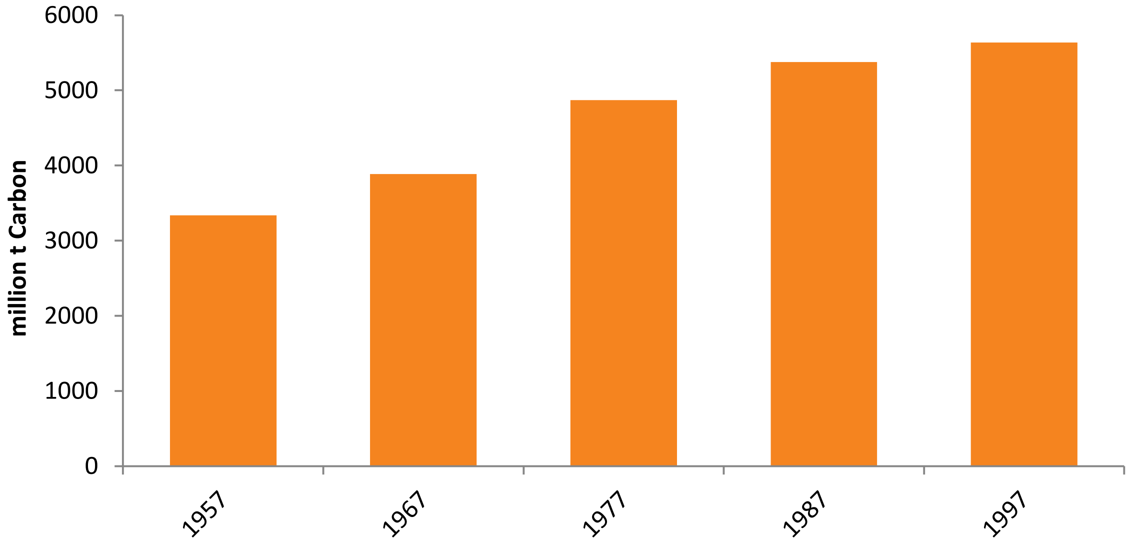
#### 4.1.2.4 Forest growing stock / above ground carbon

Since the mid-20th century the carbon stock in the US South is estimated to have increased by 69% by 1997[107]. While there are not any recently published values for the current state of US South forest carbon storage, the national forest estate has been reported to have increased approximately 20% between 1998 and 2013[108] which is likely to be indicative of what the maximum increase that could have occurred over the same 15 years to a potential store of approximately 6,700 million t C above ground.

The increasing forest productivity over the last few decades has been accompanied with rising average annual temperatures and increasing amounts of drought across the Southern States, which would likely have reduced gains in productivity without management activity. Climate variables exert a strong influence over site productivity and thus also carbon sequestration.

It has been estimated that the southern forests contain 30% of the carbon stock and account for 36% of annual carbon sequestration of the whole US.[109]

**Figure 10: US South above ground carbon 1957-1997**




### 4.1.3 Forest management practices

In recent years sustainable forest management practices have been responsible for increasing the forest carbon stock. These have included silvicultural interventions implemented throughout the duration of the rotation, to better establish and develop the

[107] Mickler *et al.*, 2004, **Forest carbon trends in the Southern United States**, *Southern forest science:past, present, and future*

[108] US Forest Service, 2015, **Baseline estimates of carbon stocks in forests and harvested wood products for nation forest system units (Two baselines: 1990-2013, 2005-2013), Southern Region**

[109] Johnsen, K.H. et al., 2014, **Productivity and carbon sequestration of forests in the southern United States.** *In: Climate change adaption and mitigation management options A guide for natural resource managers in southern forest ecosystems CRC Press*

desirability and uniformity of trees left for future harvesting. This was a fundamental shift from the historical approach of exploitatively removing the best trees at clearfelling, and leaving the poorer stems stands from which the stand was expected to naturally regenerated from. This process is sometimes referred to as 'high grading'. The result of this approach was a negative feedback loop whereby the poorer and poorer genetic material is artificially selected to reproduce by subsequent harvests, generating degraded forests.

The specific management interventions applied to hardwood and softwood forests respectively differ slightly due to growth rates, site conditions and the favoured and targeted end use market for the timber. Generally the silviculture of hardwood stands involves weeding and thinning out less desirable trees. Harvesting is through clearcutting, shelterwood or selective systems, and regeneration is natural based on seeds provided by retention wood[110]. Softwood stands are also thinned: First and second thinnings are conducted in the majority of the forests in industrial use at 10-20 years and 16-30 years, respectively. Final harvest is usually by clear cutting, with managed stands reaching harvest age much sooner than unmanaged stands. Increasingly regeneration of softwood plantations is through planting of native species following ground preparation.

Unlike the other case studies, the Federal government has rather little authority on private forest land, and the owners are free to sell the land or change the way it is used. However, lower level (State, County and Parish) forest management laws vary, but none have set annual allowable harvest levels for private forestland, which potentially has implications for overharvesting as discussed in Section 3.2.2.

### 4.1.4 Wider benefits of SFM

The active, productive forest ecosystems in the US South provide a wide variety of social, environmental and economic benefits: water and air quality management, recreation, wildlife habitat, timber and fibre production and natural beauty. Looking back at the history of exploitative high grading, it is apparent that sustainable forest management has been a key factor in both realising and increasing these benefits.

The forest industry is a significant employer in the US South providing a livelihood for around 200,000 people in 2016, of which 16% were involved in forestry and logging (including timber transport), 81% in wood processing industries and 3% in support roles. Without continued sustainable forest management, rural areas are sure to suffer as a result of increased unemployment and/or migration away in search of employment, and consequent reduced tax incomes impacting local services.

Sustainable forest management practices in the US South have been shown to provide habitat for native birds and mammals[111]. Biodiversity is important in the forest ecosystem acting as natural checks on pests (of commercial trees) as well as providing recreational value to visitors of the forest. The mosaic effect at landscape scale of patches of

[110] Hicks *et al.*, 2004, **Silviculture and management strategies applicable to southern hardwoods**, *US Department of Agriculture, Forest Service, Southern Research Station*

[111] Allen *et al.*, 1996, **Pine Plantations and Widlife in the Southeastern United States: An Assessment of Impacts and Opportunities,** *US Department of the Interior, National Biological Service Report*

plantations at different stages of development provides suitable habitat characteristics for them to live in: for example the higher level of ground cover in recently thinned stands or the density of the canopy in more mature forest will favour or deter different woodland species respectively. Likewise water and air quality is also improved by the presence of sustainably managed forests.

While undoubtedly unmanaged forest stands could provide these ecosystem services, these stands would be left more susceptible to natural disturbance, and potentially ill-equipped to adjust to the changing climate, and would not be producing timber and fibre that provide economic and social benefits, replacing non-renewable alternatives.

Since the majority of forestland in the US South is under private ownership, the absence of forest management and harvest incomes would also put the land at risk from potentially more profitable uses such as agriculture or urban development, especially given the somewhat limited regulation on land-use in the South. Urban development in the South has been relatively high since the mid-20th century due to climate and socio-economic factors, and this has been highlighted as a risk which might cause fragmentation of the forest leading to a reduction in the ecosystem services garnered[112]. The continued sustainable management of the forest based on an income for timber and wood products would mitigate this risk.

## 4.2 Finland

Finland has a long history of forest management and is considered by many to be at the forefront of sustainable forestry practices. Finnish forest management is based on forest regeneration after final felling. Sustainable forestry relies on decades of research searching to determine the best forest management practices, which are constantly being developed.

Only a few centuries ago Finnish forests were severely degraded as forests were converted into agricultural land and trees were cut for profit without implementing any forest management practices after the felling. Since then the regeneration of forests has been carried out by implementing forest management practices.[113]

### *4.2.1 Forest Industry Overview*

Over the last few decades forest ownership structure has remained the same. Most of the forests are privately owned (61%), 25% of forests are owned by state, 8% by companies and 5% by other owners.[114]

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[112] Alig *et al.*, 2010, **Conversions of forest land: trends, determinants, projections, and policy considerations,** *In Pye et al. Advances in threat assessment and their applications to forest and rangeland management, Gen. Tech. Rep, US Forest Service*

[113] Gelman *et al.*, 2013, **HENVI Workshop 2013: Interdisciplinary approach to forests and climate change,** *Helsinki University Centre for Environment, HENVI*

[114] Luke, 2013, **Ownership of forest land (1000 ha) by inventory, region and ownership category**, *Statistics database. Available at: http://statdb.luke.fi/PXWeb/pxweb/en/LUKE/LUKE__04%20Metsa__06%20Metsavarat/1.07_Metsamaa_omistajaryhmittain.px/?rxid=dc711a9e-de6d-454b-82c2-74ff79a3a5e0*

The main consumer of domestic wood is pulp industry (51%), which has been dominating the forest sector for decades. Wood processing industry consumes 37% of domestic wood, of which sawmill industry consumes 88%, and energy sector consumes 12%[115].

Many forest companies own forests, but the share of company-owned forests from total forest area is relatively low. For example UPM owns 570,000 hectares of forests in Finland, but less than 20% of its raw material comes from its own forests[116]. However, forest companies might also manage the forests of private owners. For example three Finland's largest forest industry companies, Stora Enso, UPM and Metsä Group, all offer forestry services, such as forestry work, wood sales, drainage and tax services[117]. Even though companies own a small share of total forest area they are heavily engaged with the private forest owners. For example Stora Enso works with 50,000 private forest owners[118].

Wood industry by-products are efficiently used by both forest industry and energy sector. In 2016 almost 26 million $m^3$ of forest industry by-products and waste wood was consumed. Nowadays many pulp and paper mills are integrated to plants that utilize by-products to produce heat and electricity or for example chemicals[119].

In 2016 seedling stand management (24%), forest cultivation (20%) and forest improvement practices (17%) accounted for over 60 % of total forest management costs. Three quarters of forest cultivation area was planted and one quarter was seeded. From total forest felling area 22% was clear-cut and 4% was natural regeneration felling. The share of first thinnings was 21 % of total felling area and the share of other thinnings was 47 %[115].

### *4.2.2 Forestry development*

#### *4.2.2.1 Total forest area*

Finland's forests are mainly coniferous and pine is the dominant species. Finland's forest area has remained in around 20 million hectares for decades. Figure 11 shows the forest area distribution over previous 10 years for coniferous and broadleaved forests in Northern and Southern Finland. Both the forest area and the species distribution have remained stable.

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[115] Luke, 2017, **Ruoka- ja luonnonvaratilastojen e-vuosikirja 2017,** *Available at: https://jukuri.luke.fi/bitstream/handle/10024/540980/luke-luobio_81_2017.pdf?sequence=1&isAllowed=y*

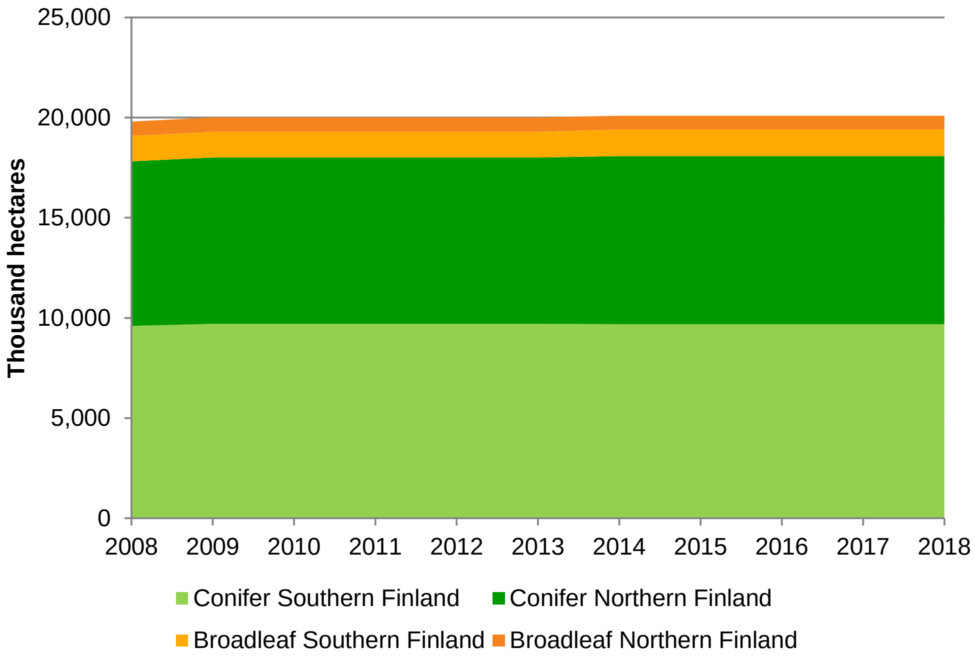
[116] UPM, 2018, **Metsät merkitsevät niin paljon muutakin kuin puuta,** *Available at: http://www.upm.fi/vastuullisuus/metsat/metsat-puuviljelmat/Pages/default.aspx*

[117] Metsälehti, 2018, **Apua ja neuvoja metsänhoitoon: Palveluntarjoajat,** *Available at: https://www.metsalehti.fi/metsanomistus/uuden-metsanomistajan-tietopaketti/#palveluntarjoajat*

[118] Palokallio, 2017**, Stora Enson uusi metsäjohtaja tyytyväinen puukauppaan,** *Maaseudun tulevaisuus. Available at: https://www.maaseuduntulevaisuus.fi/mets%C3%A4/stora-enson-uusi-mets%C3%A4johtaja-tyytyv%C3%A4inen-puukauppaan-1.186657*

[119] Maa- ja metsätalousministeriö, 2018, **Metsäteollisuus Suomessa,** *Available at: http://mmm.fi/metsat/puun-kaytto/metsateollisuus-suomessa*

**Figure 11: Forest area in Finland by type and region over previous 10 years**




Source: Luke[120]

### *4.2.2.2 Maximum mean annual increment*

The mean annual increment has been increasing for decades for all main species in Finland. Productivity varies greatly between the North and South: in Southern Finland the average current annual increment for all spruce forest areas is around 2.6 $m^3$/ha/yr, whereas in Northern Finland this drops to only 0.6 $m^3$/ha/yr[121]. This is also seen in the maximum MAI ranges across Finland[122]. Figure 12 shows the typical ranges of maximum MAI for pine, spruce and birch: the most common species in Finland. Pine is the most productive species, and birch the least. The highest maximum MAI values represent the best growing sites in the southern coastal area, which contains only small forest areas. Most of the forests are located in areas where the climatic conditions are much less favourable than in the southern coastal region.

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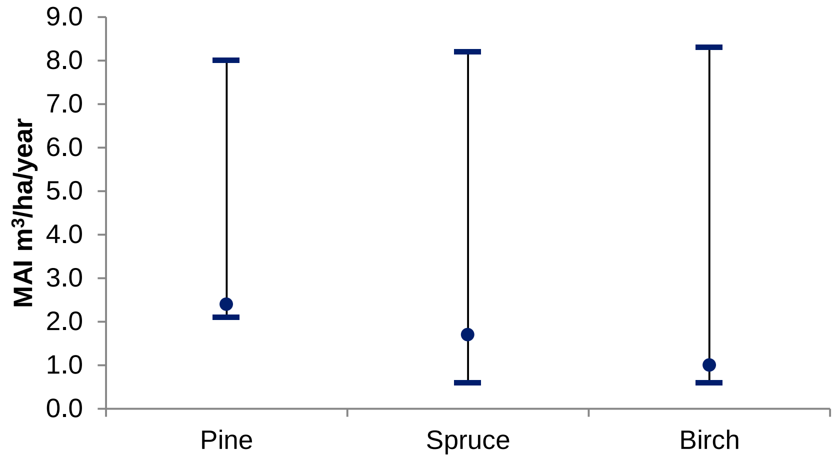
[120] Luke, **Tree species dominance and pure and mixed stands on forest land (1000 ha),** *Statistics database. Available at: http://statdb.luke.fi/PXWeb/pxweb/en/LUKE/LUKE__04%20Metsa__06%20Metsavarat/1.12_Puulajien_vallitsevuus_ja_metsikoiden.px/?rxid=93caba1c-edc1-452e-a7d0-df28b5c670a0*

[121] Luke, **Mean annual increment of growing stock on forest land by inventory, region and tree species,** *Statistics database. Available at: http://statdb.luke.fi/PXWeb/pxweb/en/LUKE/LUKE__04%20Metsa__06%20Metsavarat/1.25_Puuston_keskikasvu_metsamaalla.px/table/tableViewLayout1/?rxid=dc711a9e-de6d-454b-82c2-74ff79a3a5e0*

[122] Hynynen *et al.*, 2005, **Tuottava metsänkasvatus,** *Metla*

**Figure 12: Maximum MAI ranges for the most prevalent conifer and broadleaved species in Finland**

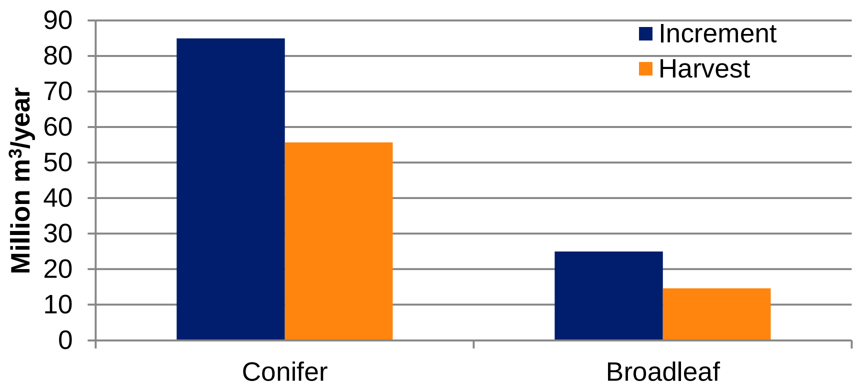



Sources: Luke [121], Hynynen[122]

### *4.2.2.3 Growth to removal ratio*

Since the 1970's the average annual increment has been significantly higher than the harvests. Within the last decade the average increment in Finland's forests has been over 100 million $m^3$ annually. Figure 13 shows the current level of mean forest increment and harvests for coniferous and broadleaved forests. Around 66 % of annual increment of conifers is harvested and almost 60 % of annual increment of broadleaf is harvested, which means that at least from timber production point of view forestry is sustainable.

**Figure 13: Forest average increment versus 2016 harvest**




Source: Luke[123 124]

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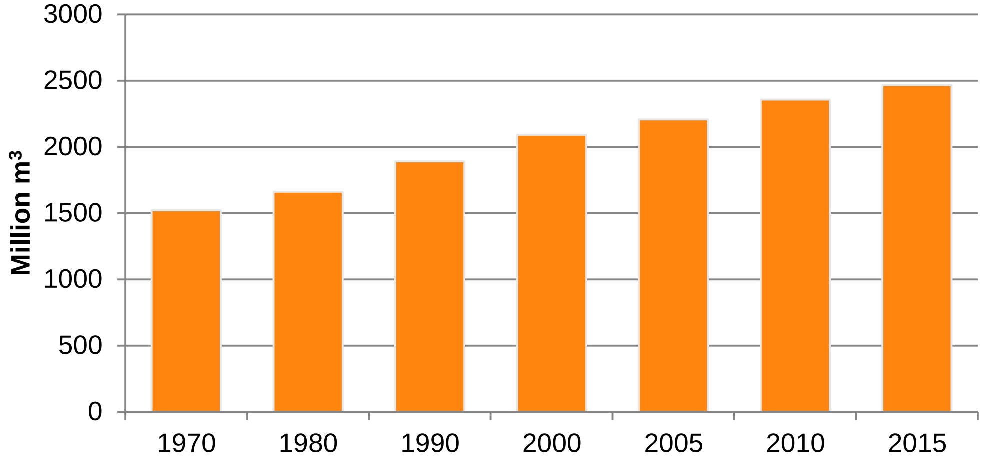
[123] Luke, **Annual increment of growing stock on forest land and on poorly productive forest land by inventory, region and tree species,** *Statistics database. Available at: http://statdb.luke.fi/PXWeb/pxweb/en/LUKE/LUKE__04%20Metsa__06%20Metsavarat/1.24_Puuston_vuotuinen_kasvu_metsa_ja_kitu.px/*

#### *4.2.2.4 Forest growing stock*

Since the beginning of the 20th Century the volume of growing stock has increased from 1500 million $m^3$ to some 2500 million $m^3$ even though forest area has remained nearly the same[129]. Figure 14 shows the development of forest growing stock in Finland over recent decades. Increase in forest growing stock is attributed to efficient regeneration and good forest management practices.

**Figure 14: Forest growing stock in Finland**




Source: Luke[125]

According to the most recent national forest inventory (NFI12), that was carried out in 2014-2016, annual forest growth was 109.9 million $m^3$ [126]. Most of this growth comes from forests that are dedicated to forestry, as forest growth in protected forests is only 3 million $m^3$ per year(the area for protected forests is much smaller than the area dedicated for forestry). Within the last decade, around 52 million $m^3$ of wood has been harvested every year. The carbon stock in Finland's forests has been growing 20-50 million $tCO_2$ each year for the last 20 years.[127] Carbon sequestration has been around 30 million $tCO_2$ for

[124] Luke, **Annual increment of growing stock on forest land and on poorly productive forest land by inventory, region and tree species**, *Statistics database. Available at: http://statdb.luke.fi/PXWeb/pxweb/en/LUKE/LUKE__04%20Metsa__06%20Metsavarat/1.24_Puuston_vuotuinen_kasvu_metsa_ja_kitu.px/table/tableViewLayout1/?rxid=dc711a9e-de6d-454b-82c2-74ff79a3a5e0*

[125] Luke. **Growing stock volume on forest land and poorly productive forest land by tree species.** *Statistics database. Available at: http://statdb.luke.fi/PXWeb/pxweb/en/LUKE/LUKE__04%20Metsa__06%20Metsavarat/1.16_Puuston_tilavuus_metsa_ja_kitumaalla_pu.px/?rxid=dc711a9e-de6d-454b-82c2-74ff79a3a5e0*

[126] Luke, 2017, **Valtakunnan metsien inventointi: Puuston kasvu noussut edelleen – Pohjois-Suomessa metsät järeytyvät**. *Available at: https://www.luke.fi/uutiset/valtakunnan-metsien-inventoinnin-tulosjulkistus-2017/*

[127] Sievänen *et al.*, 2012. **Suomen metsäenergia- ja hiilivarat ja niiden käyttö ilmastonmuutokseen sopeutumisessa**. *Metlan työraportteja* ***240***

the past 25 years[128]: Table 5 shows the annual forest carbon sequestration experienced in years 1990 – 2013[129]. According to a recent publication, the annual forest carbon sequestration is 28.3 million $tCO_2$ [130].

**Table 5: Annual forest carbon sequestration in Finland's forests (million tCO2 equivalents)**

| | 1990 | 1995 | 2000 | 2005 | 2010 | 2011 | 2012 | 2013 |
|---|---|---|---|---|---|---|---|---|
| **Total forest land** | **20.4** | **19.6** | **26.4** | **37.8** | **34.1** | **32.9** | **35** | **26.4** |
| **Harvested wood products** | **4.3** | **6.1** | **8.2** | **3.4** | **3.9** | **3.9** | **3.4** | **3.4** |

Source: Seppälä, J.et al. (2015)

### 4.2.3 Forest management practices

Only a few centuries ago Finland's forests were heavily degraded, but due to forest management activities such as peatland drainage, fertilization, well-planned harvesting operations and effective regeneration Finland's forests now containing more wood than at the beginning of the century. Within the last decades sustainability and biodiversity issues have been taken more into consideration, even in forest legislation. Nowadays forest management practises like peatland drainage, deep ploughing of forest soil and the use of herbicides have been forbidden. Forestry and felling operations are prevented in areas that are important for biodiversity preservation, and living and dead trees are left in felling areas to increase natural regeneration[113]. Dead trees are also important for forest biodiversity, and on productive forest land there is around 5.7 $m^3$ of dead wood per hectare[131], although this varies between the North and South of Finland[126].

Growing stock and forest growth has been increasing in Finland for the last 40 years and the reason for that is evolving forest management practices. Finnish forest legislation has been obligating forest regeneration by seeding or planting after final felling for over 100 years[132]. The goal of regeneration is to "create a fully productive stand with a suitable species composition in a reasonable period of time". Successful regeneration is attained by mechanical soil preparation and ensuring that other vegetation does not take living

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[128] Pohjala, P. 24.05.2017. **Tutkijat yksimielisiä: Suomen metsien hiilivarastot kasvavat hallituksen biotaloussuunnitelmista huolimatta**. *Suomenmaa. Available at: https://www.suomenmaa.fi/uutiset/tutkijat-yksimielisia-suomen-metsien-hiilivarastot-kasvavat-hallituksen-biotaloussuunnitelmista-huolimatta-6.3.242393.d41ee6ef79*

[129] Seppälä *et al.*, 2015. **Metsien hyödyntämisen ilmastovaikutukset ja hiilinielujen kehittyminen**, *Ilmastopaneelin raportti 3/2015*

[130] Pohjala, 2017, **Luke: Metsien vuosittaiset hiilinielut huomattavasti luultua suuremmat, kaksinkertaistuvat edelliseen arvioon nähden,** *Maaseudun tulevaisuus. Available at: https://www.maaseuduntulevaisuus.fi/mets%C3%A4/luke-metsien-vuosittaiset-hiilinielut-huomattavasti-luultua-suuremmat-kaksinkertaistuvat-edelliseen-arvioon-n%C3%A4hden-1.182142*

[131] Luke, 2017, **Finland's forest facts 2017**. *Available at: https://www.luke.fi/wp-content/uploads/2017/06/finlands-forests-facts-2017-www.pdf*

[132] Luke, 2018, **Metsänhoito,** *Available at: https://www.luke.fi/tietoa-luonnonvaroista/metsa/metsanhoito/*

space from the seedlings[133]. Forest regeneration is considered to be completed if the site contains a seedling stand within 10-25 years after the final felling. To achieve this state the seedling stand must be densely and evenly stocked, with an average height greater than 0.5 meters and no other vegetation should be an immediate threat to the seedlings growth[134].

While forest growth in Finland has increased during the past decades due to silvicultural activities other factors such as effective prevention of forest fires and other natural disasters have also increased forest growth. Increases in carbon sequestration are also a result of converting understocked forest stands towards full-stocking potential, expanding forest areas and improving knowledge regarding harvesting levels, harvest sites, rotation lengths and forest regeneration. This has largely been a result of years of focused research and development of decision support tools[113].

In addition to decision support tools, The Ministry of Agriculture and Forestry finances a collection of forest management guidelines that can be downloaded for free by anyone: Tapio's Best Practises for Sustainable Forest Management is aimed at forest owners to guide them toward forest management best practices. All these management practises are economically, ecologically and socially sustainable. These guidelines are created together with forest owners and multiple specialists among the forest, energy and environment sector. The guidelines differ depending on the tree species, soil type, growth habitat etc.[135] .

Although the level of forest management is very good in Finland, there are still improvements possible. Many forests experience delays to silvicultural operations: According to the latest national forest inventory there are 795,000 hectares of seedling stands that should have already been tended. In almost a million hectares of young forests the first thinning is late.[126] If seedling stands are not tended in time it will decrease the possibilities of forest utilisation and carbon sequestration in the long term. This can importantly have a knock-on effect on forest owners harvesting income in the future, losing around 300-400 EUR per hectare.

Sustainability issues and nature values play an important role in forestry legislation, recommendations, guidelines and certification in Finland, and this should ensure that forest management continues to improve and move towards even more sustainable practices.

#### *4.2.4 Wider benefits of SFM*

The forest industry in Finland employs approximately 42,000 people directly and the entire value chain employs around 150,000, and as with the other case studies, these jobs are mostly concentrated in rural areas. Additionally Production from forests also accounts for

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[133] Luke, 2012, **Main lines of forest management in Finland's coniferous forest zone**, *State of Finland's Forests 2012: Finnish forests and forest management in a nutshell. Available at: http://www.metla.fi/metinfo/sustainability/SF-1-main-lines.htm*

[134] Finlex, 2018, **Metsälaki 8**, *Uudistamisvelvoitteen täyttäminen. Available at: http://www.finlex.fi/fi/laki/ajantasa/1996/19961093*

[135] Tapio, 2014, **Metsänhoidon suositukset,** *Metsätalouden kehittämiskeskus Tapio ja Metsäkustannus Oy.*

over 20% of Finlands export value[136]. Thus loss of forest management would have severe consequences for the Finnish economy.

Forests in Finland are not only used for timber production. They have many other uses, such as game and reindeer husbandry, berry and mushroom picking, recreation and nature tourism, protection of the environment and biodiversity of forest nature, and cultural value of forests. In the 21st century non-wood based productivity is mainly seen in reindeer husbandry, picking berries for commercial use, hunting and Christmas tree farming[137]. Without forest management access would be restricted and these activities may be difficult to conduct.

Sustainable forestry enables timber production without pressuring forest biodiversity too much. Forest biodiversity is secured with Forest Biodiversity Programme called METSO[138]. METSO is a voluntary protection program for forest owners who want to protect the biodiversity of their forests. The program has specific targets for 2025. The plan is to reach 96,000 hectares of conserved area by 2025. Owners can voluntarily offer areas for private conservation area, state can acquire areas or the area can be placed under protection for a certain period of time[139]. Around 12 % of total forest area is protected, which equals to 2.7 million hectares of forests. The amount of protected forests has tripled over the past 40 years[131].

## 4.3 United Kingdom

The UK represents an interesting case because as recently as the beginning of the last century forest cover was at a low point of ~4.7% of total land area. It has since recovered due to a range of public and private afforestation efforts to a current level of ~13% of land area.

Sustainable forest management is required for any commercial forestry operations, as a felling licences and grants cannot be obtained without government approved plans in place based on compliance with the UK Forestry Standard for sustainable forest management. Additionally, the government agencies associated with forestry strive to encourage wider adoption of forest management because of the wide benefits it brings.

Sustainable forest management in the UK has been helping to transition plantations from monocultures to more mixed stands that are more resilient to natural disturbance from wind, pests and disease. In the absence of forest management, it is likely that legacy monocultures would be susceptible to such damage and associated losses would see carbon storage declining in the UK's forests.

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[136] Finnish Forest Industries, 2016, **Forest Industry**, *Available at: https://www.forestindustries.fi/statistics/forest-industry/*

[137] Lähtinen, 2010, **Metsien eri käyttömuodoista saatavien hyötyjen taloudellinen arvo ja niihin liittyvä yritystoiminta Suomessa,** *Metsätieteen aikakauskirja 2/2010*

[138] Maa- ja metsätalousministeriö, 2018, **Talousmetsien monimuotoisuus,** *Available at: http://mmm.fi/talousmetsien-monimuotoisuus*

[139] Metsonpolku, 2016, **METSO – Etelä-Suomen metsien monimuotoisuusohjelma**, *Available at: http://www.metsonpolku.fi/fi-FI/METSOohjelma*

### 4.3.1 Forest Industry Overview

Modern forestry in the UK has its origins since the First World War when a concerted effort was put into UK forestry. The Forestry Commission was established in 1919 to provide a strategic supply of timber to avoid importing in times of war[140].

Following the Second World War there was a boom in plantation expansion, with Sitka spruce being the preferred species due to its favourable growth in the UK climate. This first boom in planting was mostly accomplished by the Forestry Commission, with some grant schemes in place for private forest owners to establish forests. It was not until the 1970s that private forestry really took off in the UK when grant and aid schemes were coupled with tax breaks for forest ownership. This afforestation mostly consisted of monocultures of exotic species such as Sitka spruce which grow particularly well in the UKs climate. These forests were mostly planted on drained upland sites: a practice which is now avoided to avoid excessive soil carbon release[141]. As a result the UK has been left with a legacy of these introduced stands, and a wider forest industry that is focused on production from them.

In more recent years the rate of afforestation has declined, and new forest area established in the UK in the past couple of years has been less than 10,000 ha/yr[142], although there are several projects aiming to increase afforestation in the UK (e.g. through woodland creation grants[143]). However, while afforestation (and reforestation) has seen a shift in recent years towards native broadleaf planting (see Figure 15), this may not continue to be sustainable due to the forest industries requirements for softwood.

Forest ownership is split between the state and private owners as shown in Table 6. Private owners include owners of large historic estates, charitable trusts, forest investment funds, as well as smaller owners who have a variety of use objectives. While estimates suggest there are approximately 40,000 people with ownership of forestland >5ha in the UK, the largest areas of private ownership are concentrated in relatively few owners, with Scotland being reported as having some of the largest average forest holding size in Europe at 259 ha/owner[144].

**Table 6: UK Forest ownership**

| | Area ('000 ha) | | Area (%) | |
|---|---|---|---|---|
| | **Conifer** | **Broadleaf** | **Conifer** | **Broadleaf** |
| State-owned | 733 | 130 | 85% | 15% |
| Private-owned | 885 | 1,418 | 38% | 62% |
| **Total** | **1,618** | **1,548** | | |

Source: Forestry Commission[142]

[140] Aldhous, 1997, **British forestry: 70 years of achievement**, *Forestry, Vol. 70*

[141] Cannell, 1999, **Growing trees to sequester carbon in the UK: answers to some common questions**, *Forestry* ***72(3)***

[142] Forestry Commission, 2017, **Forestry Facts and Figures 2017,** *Forestry Commission Publications*

[143] UK Government, 2017, **£13 million fund to increase England's woodland,** Press release: https://www.gov.uk/government/news/13-million-fund-to-increase-englands-woodland

[144] Woodland Trust, 2011, **The State of the UK's Forests, Woods and Trees: Perspectives from the sector**

While the 3.2 million hectares of UK forest are split evenly between conifer and broadleaf, commercial forestry is almost entirely concentrated in conifer production with softwood, representing 95% of volume removed from forests in 2016[145]. The majority of wood is supplied by the private sector, although public forests provided between 41-46% of UK wood since 2012.

The largest wood consuming industry in the UK is sawmilling. In 2017 sawmills consumed 6.6 million green tonnes of UK grown roundwood in 2017, representing more than half of UK roundwood production (totalling 11.3 million green tonnes of softwood and hardwood)[145]. As mentioned above, sawmills are focused on softwood milling, with only a limited number of small hardwood mills. The next largest consumers are woodfuel (2.0 million green tonnes), wood-based panels (1.2 million green tonnes), and pulp and paper (0.4 million green tonnes). The remaining 0.8 million green tonnes was consumed by round fencing, shavings and exported.

Despite the increase in forest area over the past century, the UK is still heavily reliant on importing wood and wood products, with imports making up close to 80% of UK wood needs.

### *4.3.2 Forestry development*

#### *4.3.2.1 Total forest area*

The total UK forest area is shown in Figure 15, with the vast majority of area being conifer plantations in Scotland and broadleaved woodland in England. Most gains in the past decade have been in broadleaved area, with some minor losses to coniferous areas which some in the forest industry have pointed to as a possible risk to sustainability of forest industry. Traditional wood processing industries need a consistent softwood volume to operate, and so ensuring a continued (and potentially expanded) conifer area is important and has been acknowledged by some areas of government[146].

Over the past decade English forests have increased the level of forest management from just under 50% of forests to 58% of forests[152], broadleaved woodlands remain largely unmanaged. In Wales the proportion of active management increases to approximately 66% of the area[147] and while there is no apparent published proportion of forest actively managed, the high proportion of commercial conifer crops would suggest that it is higher still than the Welsh proportion. Northern Ireland likewise has no published area, but should sit within the same range as the rest of the UK. Goals are in place for some parts of the UK to increase active forest management and realising these goals presents an opportunity to increase carbon stocks in existing UK forests.

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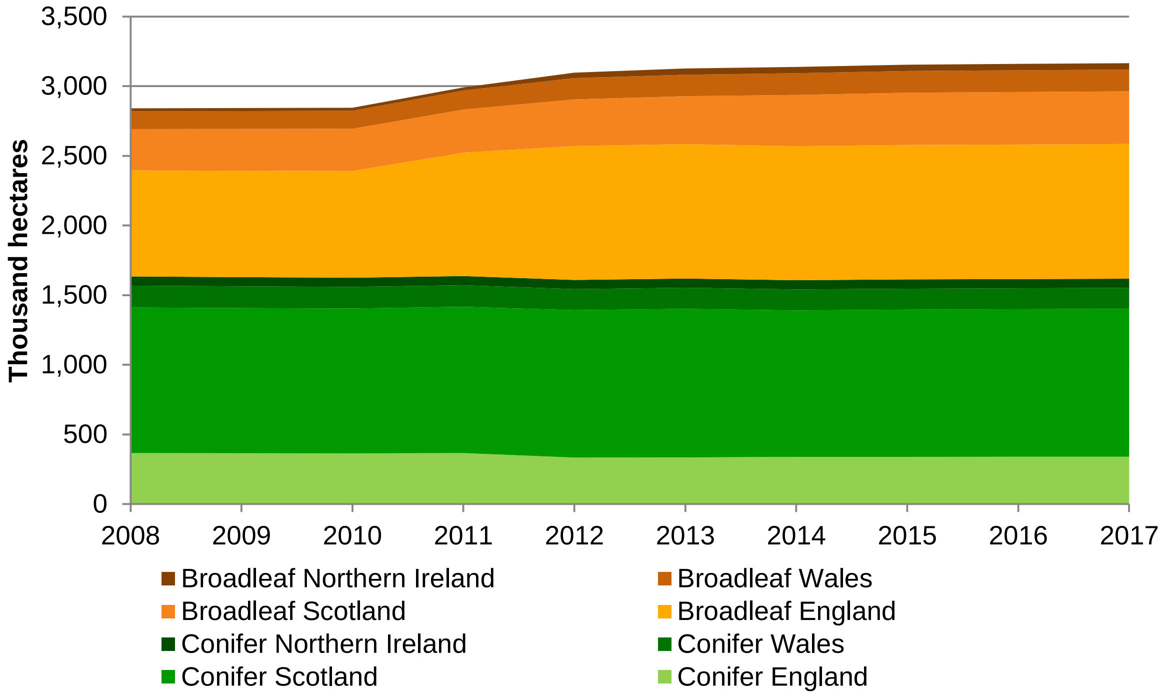
[145] Forestry Commission, 2017, **Forestry Statistics 2017**, *Forestry Commission Publications*

[146] Tatchell-Evans, 2016, **SPICe Briefing: Scottish Forestry**

[147] Warren-Thomas & Henderson, 2017, **Woodlands in Wales: a quick guide**, *National Assembly for Wales Research Service*

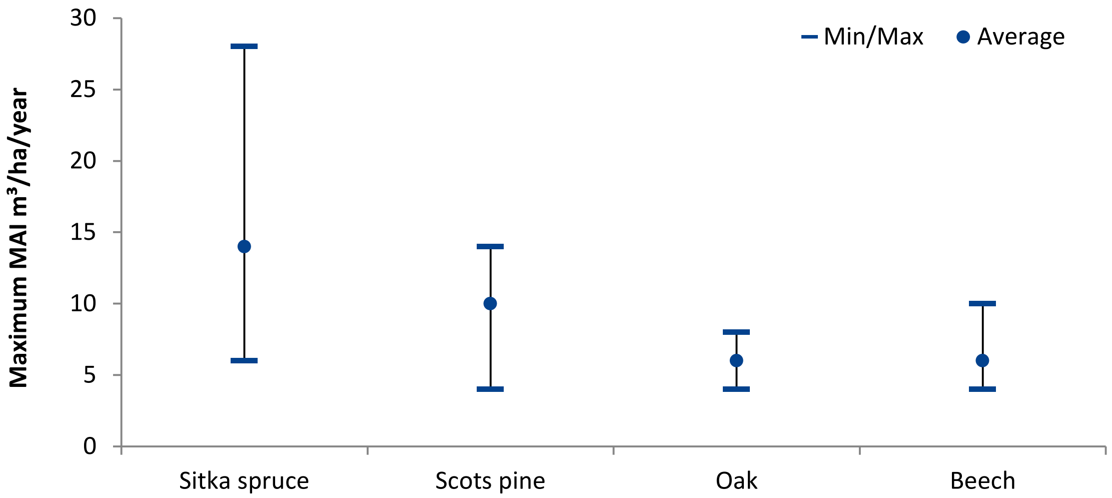
**Figure 15: Forest area in UK by country and type over previous 10 years**




### *4.3.2.2 Maximum mean annual increment*

The maximum MAI varies between species in the UK. Sitka spruce shows the highest maximum MAI of all species, which goes some way to explaining its prevalence in the UK. Some areas of Sitka plantations can achieve maximum MAI of 28 $m^3$/ha/yr, the average productivity in the UK is around 14 $m^3$/ha/yr in Sitka spruce. Other species, and especially broadleaved species have much lower maximum MAI as can be seen in Figure 16. This low productivity must be taken into consideration if managing woodlands for carbon storage is important, as it will take such species much longer to accumulate carbon, though by the time such species reach biologically optimal rotation age individual trees will represent much greater carbon stores.

**Figure 16: Maximum MAI ranges for the most prevalent conifer and broadleaved species in the UK**




Source: Forestry Commission[148]

### 4.3.2.3 Growth to removal ratio

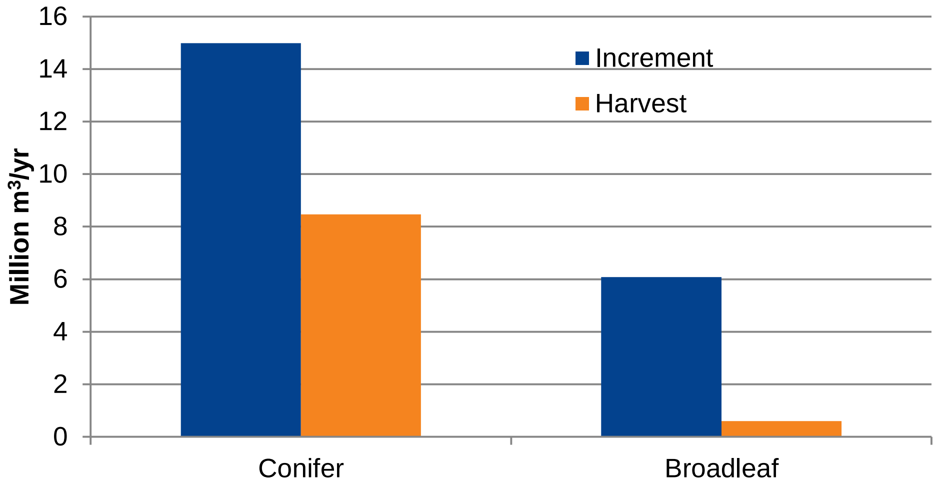
Annual increment for Great Britain (excluding Northern Ireland) over the past 5 years was estimated to be approximately 15.0 million $m^3$/yr for conifers[149] and an average of 6.1 million $m^3$/yr for broadleaves[150]. The harvest of conifers represents 57% of the annual increment, and the broadleaf harvest is <10% (Figure 17). With such a ratio in place it can be seen that the wood volume and carbon storage should continue to increase in the UK for the near future. Indeed, bringing more broadleaved forest into management could even increase the broadleaved increment further and allow for greater carbon accumulation.

[148] Forestry Commission, 2011, **Tree Species: A document listing the tree species included in the 2011 Production Forecast**

[149] Forestry Commission, 2012, **GB 25-year forecast of standing coniferous volume and increment**, *NFI Statistical Analysis*

[150] Forestry Commission, 2014, **50-year forecast of hardwood timber availability**, *NFI Statistical Analysis Report*

**Figure 17: Forest average increment versus 2016 harvest level**

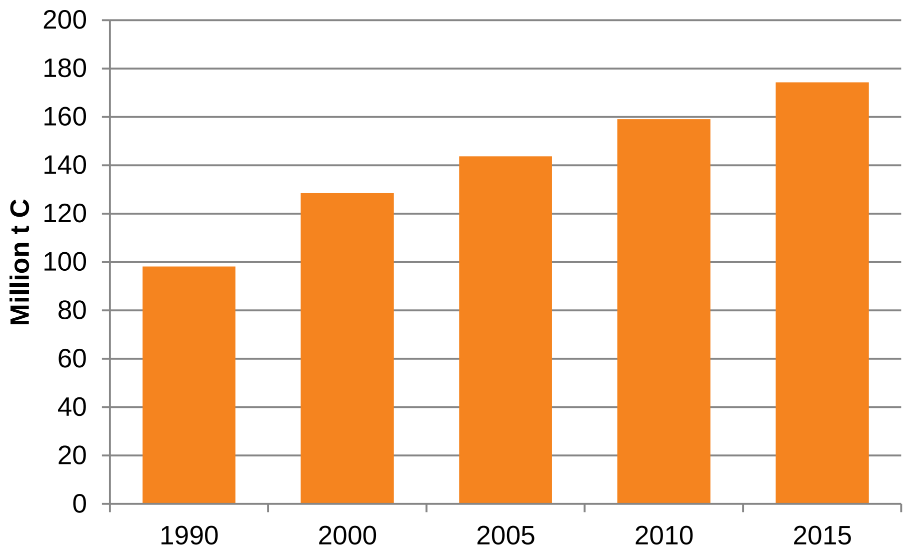



Source: Forestry Commission[145,149,150]

### *4.3.2.4 Forest growing stock and above ground carbon*

Figure 18 shows how the annual harvest levels sitting lower than the annual increment has resulted in an increase in carbon storage in the UK's forests since 1990. There has been a 77.5% increase in carbon storage above ground in this time. In addition to this carbon has also been reported as increasing in forests below-ground (roots), in dead wood and litter, and forest soils[145].

**Figure 18: UK above ground forest carbon storage**




Source: Forestry Commission[145]

### 4.3.3 Forest management practices

While historically the UK has relied heavily on monocultures of introduced species, greater public and stakeholder engagement in recent decades has led to adjustments in policy and support for forestry to shift away from this approach. Sustainable forest management, which also takes into account environmental and social aspects of forestry, whilst still allowing productivity to be enhanced has been a focus in the UK since before the turn of the century[151]. It is important to note that active forest management is encouraged by the Forestry Commission as a way of avoiding forests becoming vulnerable to deterioration and decline and is one of Forestry Commission England's headline performance indicators[152].

The UK Forest Research agency publishes a wide range of decision support tools to help managers evaluate the impact of sustainable management practices such as the Ecological Site Classification tool to test species suitability, or the ForestGALES tool to evaluate wind risk to stands. Indicators of their adoption rate are positive[153].

It is important to note that devolution of the government organisations responsible for forestry has led to more focused strategies for each of the constituent countries of the UK[154],[155],[156],[157]. Each country has differing economic, social, and environmental conditions which benefits from a more tailored approach to forest management. For example: England has a much larger proportion of broadleaved woodland compared to Scotland and Wales, and Northern Ireland is isolated geographically from the rest of the UK meaning that roundwood offtakers are more likely to be in the Republic of Ireland.

Overarching these separate strategies is the UK Forestry Standard[76], which defines standards and requirements in sections covering biodiversity, climate change, historic environment, landscape, people, and soil and water. The UK Forestry Standard was first published in 1998, and is now on its fourth revision (published in 2017). In each revision adjustments are made based on both legislation and regulation both nationally and internationally, but also incorporating relevant updates based on advances in the scientific understanding of forestry.

The Forestry Standard has pushed both afforestation and restocking to focus on establishment of mixed native woodlands, increasing species and structural diversity to realise the wider benefits (Section 4.3.4).

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[151] Mason, 2007, **Changes in the management of British forests between 1945 and 2000 and possible future trends**, *Ibis* ***149(Suppl. 2)***

[152] Forestry Commission, 2017, **Corporate Plan Performance Indicators: Headline Performance Update 31 March 2017**

[153] ClimateXChange, 2018, **Suitability and productivity (forestry),** available at: https://www.climatexchange.org.uk/research/indicators-and-trends/natural-environment/suitability-and-productivity-forestry/

[154]Forestry Commission Scotland, 2006, **The Scottish Forestry Strategy**

[155] Natural Resources Wales, 2009, **Woodlands for Wales**

[156] Forest Service Norther Ireland, 2006, **Northern Ireland Forestry: A strategy for sustainability and growth**

[157] Forestry Commission England, 2007, **England Forestry Strategy: a new focus for England's woodlands**

All forestry in the UK must comply with the standard as assessed by the Forestry Commission in England and Scotland, as well as Natural Resources Wales and the Northern Ireland Forest Service in the other parts of the UK. Adherence is required to obtain any grants or aid support in addition to being required for felling licences.

In addition to this compulsory standard there is voluntary certification which is widely adopted in the UK. Certification is possible through the UK Woodland Assurance Scheme (UKWAS), which is approved by both FSC and PEFC certification standards[158]. This builds on the UK Woodland Standard to provide stronger assurances and verification of the sustainability of management in any given forest in the UK. At present 44% of the UK's forests are certified, including all of the state owned forests[145].

### *4.3.4 Wider benefits of SFM*

A wide study of biodiversity in the UK's plantations concluded that plantation (including those established before sustainable forest management practice were common) has had some benefit to biodiversity, and this can be further enhanced by attention to factors impacting biodiversity as is practice in sustainable forest management[159] (in line with the UK Forestry Standard).

SFM also has social benefits in the UK: by actively managing and creating more forests there are greater recreational and landscape amenities, and sustainable forest management has also been shown to protect cultural history through preserving historic forest skills and protecting archaeological artefacts[160] that would be lost or become degraded if forest management was absent.

The forest industry in the UK (and associated sustainable forest management) supports a large number of jobs across forestry, wood industries, and pulp and paper, as shown in Table 7. These jobs also contribute a value of 2,116 million GBP to the UK economy (Table 7).The absence of forest management would mean no harvesting to support any of these jobs or contribution to the economy. This would lead to especially acute issues in rural areas where the majority of these jobs are located.

**Table 7: UK forest industry jobs and value added (2015)**

| | Forestry | Sawmilling | Panels | Pulp & Paper | Total |
|---|---|---|---|---|---|
| Jobs | **17,000** | **8,000** | **5,000** | **13,000** | **43,000** |
| Gross value add (Million GBP) | **626** | **429** | **323** | **738** | **2,116** |

Source: Forestry Commission[142]

[158] UKWAS, 2018, **United Kingdom Woodland Assurance Standard, Version 4.0**

[159] Humphrey *et al.*, 2003, **Biodiversity in Britain's Planted Forest: Results from the Forestry Commission's Biodiversity Assessment Project,** *Forestry Commission: Edinburgh*

[160] Willis *et al.*, 2003, **The Social and environmental benefits of forests in Great Britain,** *Report to Forestry Commission Edinburgh*

It is interesting to note that in the UK wider benefits of SFM have been attempted to be quantified through the system of natural capital accounting[161]. The public forest estate in England is reported to have almost 98.8% of its value derived from intangible benefits delivered to society in comparison to the income streams from timber marketing and recreational sales[162].

## 4.4 Uruguay

Uruguay has been selected as this case study demonstrates how the rapid development of the forest industry has drastically increased the forest area and forest carbon stock whilst simultaneously preventing deforestation. The development of the forest industry in Uruguay has happened more recently than in other regions and primarily under basic economic principles; international investors took advantage of relatively cost effective labour and good growing conditions to establish integrated forest businesses which produce wood products for the global export market.

### *4.4.1 Forest Industry Overview*

Development of a plantation resource in Uruguay began during 1975 when the government offered incentives including tax waivers on properties and subsidies for forest operations. Later the National Forest Plan and the second forestry promotion law in 1987 further subsidized new forest plantation establishment[163], and gave exemption of income tax and import and export tax duties for timber. This had a large impact on the development of plantations in Uruguay, which grew from 25,000 ha in 1987[164] to over 1 million ha in 2015[165].

Part of this expansion was done by major foreign investors who started establishing eucalyptus plantations in Uruguay in 1990. Forestal Oriental (formed partly by Shell), EUFORES (ENCE) and other Uruguayan companies (e.g. COFUSA and Forestal Caja Bancaria) also started activities in the forestry sector at this time. Other companies such as Weyerhaeuser, Fymnsa and Urupanel started operations with the aim of producing sawnwood and wood-based panels for the export market. In 2003 the first investment fund acquired land suitable for plantation establishment (GMO Renewable Resources) and this ownership type has also grown.

The second forestry promotion law benefits lasted until 2005, the loss of the subsidies as well as less favourable reforms to tax in 2007 combined with the impact of the global financial crisis impacting the export market for wood products, reduced rates of afforestation. Currently, tax benefits are limited to plantations under long-rotation management regimes (longer than 15 years), which must be made on land considered of poor agricultural or environmental value, and be run under a management plan submitted to the Ministry of Agriculture. The level of planting has subsequently lessened but remains around 20,000 ha for Eucalyptus over 2013-2017, whilst the area of pine has lessened slightly (according to government estimates) as a result of market conditions.

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[161] Office For National Statistics, 2017. **Principles of Natural Capital Accounting**

[162] Forestry Commission England, 2017, **Natural Capital Account 2016-2017**

[163] Uruguayan Government, 1987, **Act No. 15.939 on Forestry**

[164] PEFC Uruguay, 2009, **Uruguayan Forest Certification Scheme**

[165] Food and Agriculture Organization of the United Nations, 2015, **Evaluación de los recursos forestales mindiales 2015: Informe Nacional Uruguay**

The total forest area in Uruguay is now estimated to be 1.8 million ha, of which approximately 1.0 million ha is planted forest and which is available for the forest industry. Natural forest which consists of some 800,000 ha is protected from harvesting under Uruguayan law without special permits. Of the planted area around 74% is eucalyptus species and 26% is pine species.

The total annual wood consumption in Uruguay is around 10.1 million m³/year. The pulp industry is the largest consumer of wood in Uruguay (54%) followed by the bioenergy industry (19%), sawnwood (11%), woodchip (8%) and wood based panels (6%). The pulp and woodchip industries use only eucalyptus logs, whilst the sawnwood and wood based panel industries use mostly pine logs.

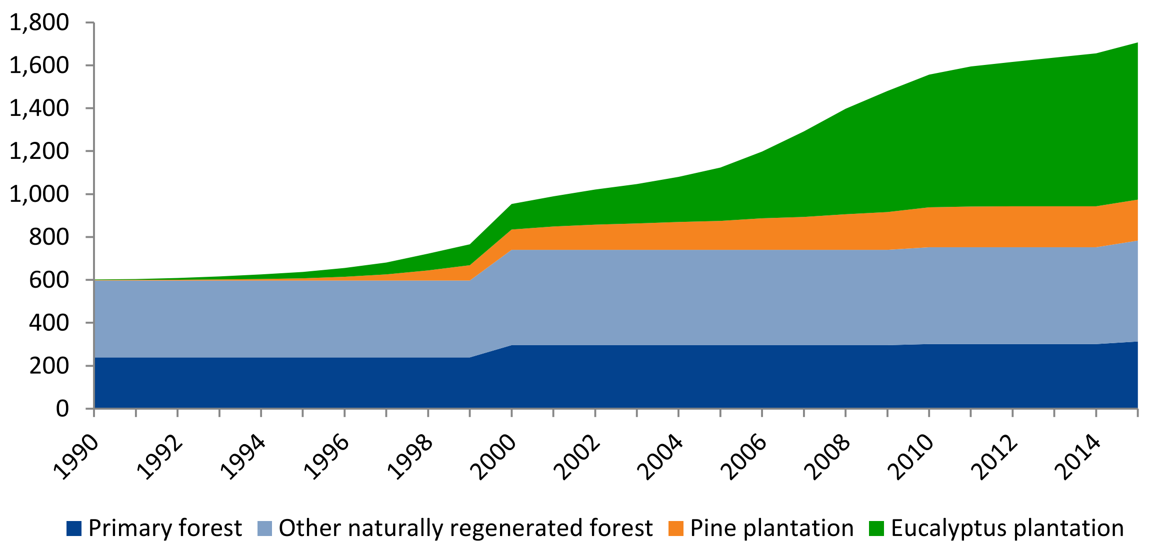
All of the planted forest area in Uruguay is under private ownership. Just over half (54%) of the plantation forest area is owned by international and vertically integrated companies, and the operators of Uruguay's two pulpmills; UPM and Montes del Plata are also the largest and second largest owners in terms of plantation area respectively. Around a third (36%) of the planted area is owned by non-integrated forest companies (mostly TIMOs and REITs) and the remainder (10%) by other small private producers.

### 4.4.2 Forestry development

#### 4.4.2.1 Total forest area

Since 1990 the total forest area in Uruguay has increased by around 131% by 2015 (Figure 19). This is mostly due to the increase in planted forest area whilst the area of natural forest types has remained relatively stable. Due to the regulatory environment in Uruguay only the planted forest should be assumed as under management and this share increased to 58% of the total by 2015.

**Figure 19: Total forest area development in Uruguay**

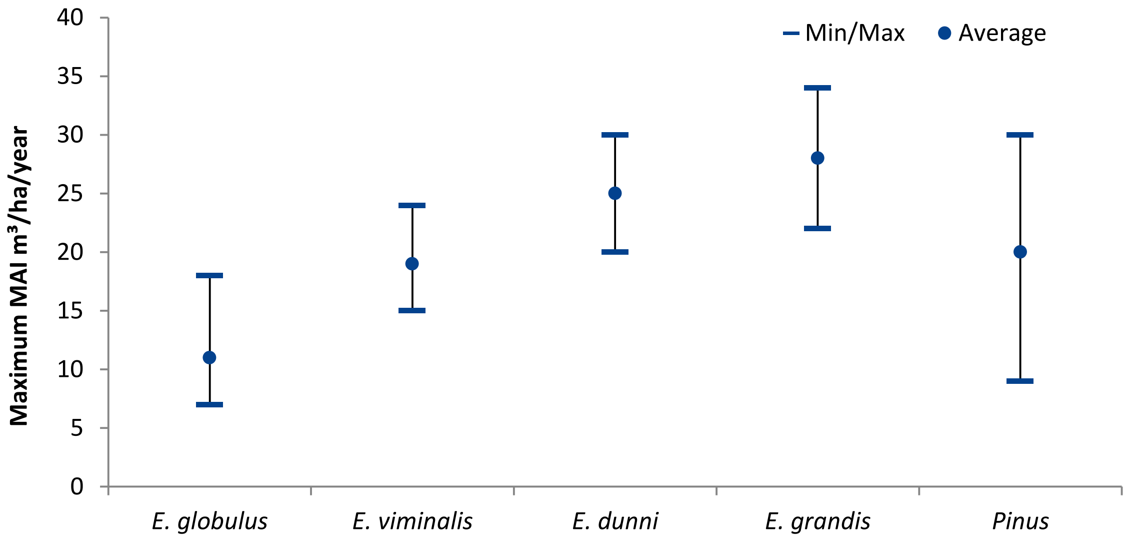



NB: The Increase in primary forest volume is a result of a revised estimate of primary forest rather than more primary forest being established. Source: FAO[165], Pöyry

#### 4.4.2.2 Increment

Forest stand increments in Uruguay typically range from 7 to 34 m³/ha/year for eucalyptus and 9 to 30 m³/ha/year for pine (Figure 20). Historically yields were lower than can be achieved presently, as plantations were predominantly planted with lower yielding *E. globulus* trees than the genetically improved and higher yielding *E. grandis* that are being used to restock planations. Following its introduction, *E. grandis* has been increasingly planted in Uruguay and now accounts for around 25% of the total planted area, and as such the average yield from forest plantations in Uruguay has increased. However, *E.dunni* is also being expanded by some owners due to its greater frost tolerance. This should lead to improved carbon sequestration due to the faster growing trees.

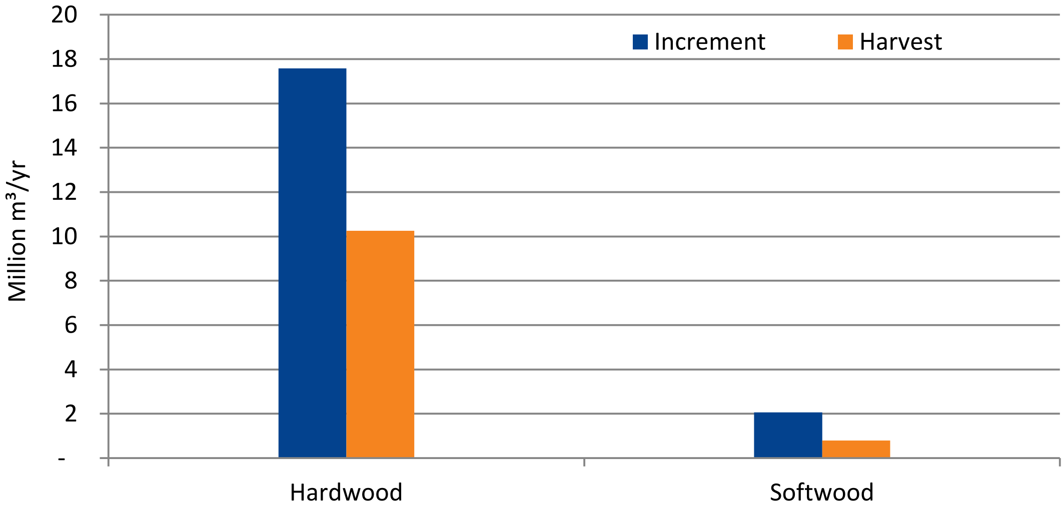
**Figure 20: Maximum MAI ranges for common species grown in Uruguay**




#### 4.4.2.3 Growth to removal ratio

The growth to removal ratio indicates that the increased harvesting levels are not depleting the volume that has been grown to date. The figure below shows that harvesting in 2015 was 59% of the net growth of hardwoods and 41% of the net growth of softwoods.

**Figure 21: Growth to removal ratio for Uruguayan plantations**

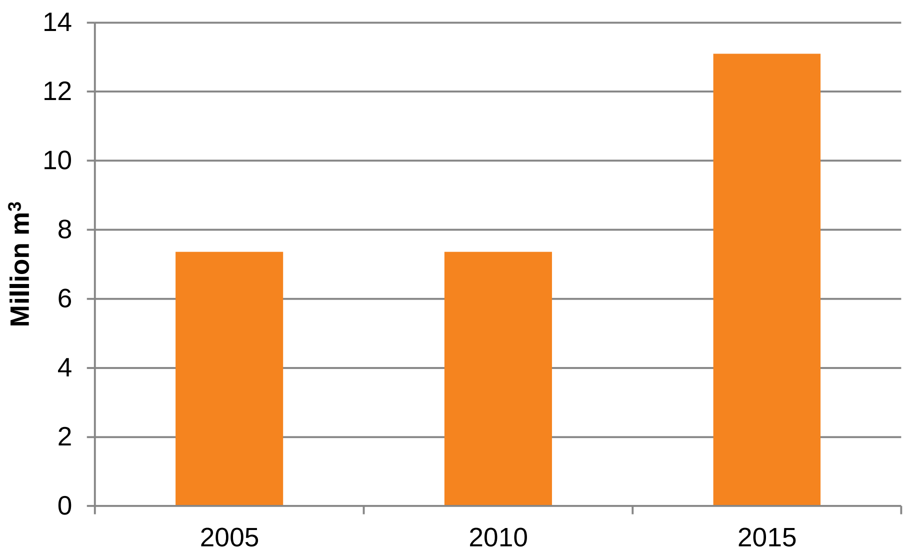



Source: Pöyry calculated

### *4.4.2.4 Forest growing stock / above ground carbon*

Due to the increased rates of planting, improved yields, and actual harvesting levels (as shown in the previous section), the forest growing stock has increased in plantation forests by 78% between 2005 and 2015 (Figure 22). At the same time, natural forests in Uruguay have also been able to increase their growing stock by approximately 5%[165].

**Figure 22: Uruguay plantation standing volume**




Source: FAO[165]

### 4.4.3 Forest management practices

In Uruguay forest management has been steered by government policy which opened the country to international investors whilst protecting the area of remaining natural forest. The Forestry Law No. 15.939 designed to protect the remaining natural forest areas by prohibiting their use and destruction, and to develop a forest industry based on a plantation grown fibre through incentivising the establishment of forest plantations and wood consuming industries.

The development of the forest industry has led to the introduction of two forest management regimes applied to plantation forests. These include the pulpwood regime and the sawlog regime, which are tailored to grow products specifically for the pulp/woodchip/bioenergy industries and sawnwood/wood based panel industries respectively. Around two thirds (67%) of the planted forest is managed under the pulpwood regime, of which all is Eucalyptus species. In this regime the stands are planted at densities of 1,333 trees per hectare, and these are usually harvested following 12-14 years of growth. The remaining 31% is managed under the sawlog regime and this consists of all the pine area and a minority of the eucalyptus, trees are planted at a higher density and harvested through several thinning operations before clearfelling the remaining crop around age 20-22 years. These regimes are designed to hold the maximum amount of fibre (and subsequently forest carbon stock) per unit of land area and as such they have contributed significantly to the increase in forest carbon stock within Uruguay. It should be noted that they are also designed to produce roundwood products that the industry can use, and so the economic sustainability of the plantations is dependent on market conditions prevailing ceterus paribus.

Around two thirds (68%) of the planted forest was managed under FSC certification in 2015. Since the forest industry in Uruguay is mostly export based its international customer base in North America and the Europe are increasingly under pressure to procure wood products from sustainably managed forests.

### 4.4.4 Wider benefits of SFM

The forest industry in Uruguay provided around 15,000 jobs directly in 2016, of which just over half (55%) were involved on forestry and logging and just under half (45%) in wood processing. Industry developments including the construction of mills have also been reported as having a significant impact on the labour market, albeit temporary. There has also been an increase in the number of skilled jobs required for the processing of pulp, which has triggered the start-up of several courses in forestry and wood science at Uruguayan Universities.

Due to the supply and demand imbalance of wood fibre in Uruguay, there is also potential to increase construction with wood domestically which would reduce emissions compared with building with concrete, and help to develop the wider forest industry in Uruguay.

Ultimately, the absence of sustainable forest management in Uruguay would result in alternative land use being applied, and the most common land use is pasture. This is often a carbon source (rather than the sink that forests provide) and would not be a positive direction for sustainable land use.

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