The Economics of Climate Resilience Agriculture and Forestry Theme: Forestry CA0401

A REPORT PREPARED FOR DEFRA AND THE DEVOLVED ADMINISTRATIONS

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Context of this report

The Economics of Climate Resilience (ECR) has been commissioned by Defra and the Devolved Administrations (DAs) to develop evidence to inform the National Adaptation Programme and the adaptation plans of the DAs. The report should be read in the context of other programmes of work on adaptation being taken forward separately.

The scope of the ECR

The ECR follows the publication of the UK Climate Change Risk Assessment (CCRA) in January 2012 and differs in scope from work envisaged prior to that date. While its original aim was to consider individual climate change risk metrics from the CCRA and specific adaptation options, this evolved as the project was considered across government departments. The current ECR therefore focuses on broader policy questions, with each report covering multiple climate risks and CCRA risk metrics. In this context, the economic assessment is broader than a quantitative assessment of costs and benefits – it concerns identifying and assessing market failures and other barriers to effective adaptation action, seeking to understand drivers of behaviour which hinder or promote the adoption of adaptation actions. The framework for assessing the costs and benefits of adaptation actions is considered in a separate phase of the ECR.

Questions addressed

The questions addressed by the ECR were chosen following cross-government engagement by Defra. They ask whether there is a case for further intervention to deliver effective adaptation given the current context – i.e. the current adaptive capacity of those involved and the policy framework. Criteria for the choice of questions by policy officials include: the current and projected degree of the climate change risk; priorities for additional evidence gathering beyond that already being considered in other work-streams, and the data and evidence currently available. Questions were deliberately broad to allow the wider context to be considered, rather than just individual climate metrics. However, this approach prevents a detailed evaluation of individual risks or localised issues being made. Detailed assessments of climate thresholds and the limits of specific adaptation options have also not been possible.

Analysis undertaken

The analysis has sought to build on existing assessments of current and projected climate change risks (such as the CCRA). The context in which sectors operate has been assessed, including the current adaptive capacity of relevant actors and the policy framework in which those actors function. Categories of actions currently being taken to adapt to climate change have been explored, including those which build adaptive capacity where it is currently low, and those which limit the adverse impacts or maximise opportunities, allowing identification of barriers to effective adaptation. The case for intervention is then presented.

The degree to which an adaptation action is likely to be cost-effective requires more detailed assessment, reflecting the particular context in which adaptation is being considered.

This report is underpinned by stakeholder engagement, comprising a series of semi-structured interviews with sector experts and a range of other stakeholders. This has enabled the experiences of those who undertake adaptation actions on the ground to be better understood. We are grateful to all those who have given their time.

1 Executive Summary

The focus of the analysis

This report addresses the question:

"What is the case for further action in relation to climate change adaptation for forest productivity and associated ecosystem services?"

Particular focus was requested by Defra on conifers and broadleaf productivity and forestry land-use and its impact on ecosystems and ancient woodlands[1].

What is the exposure of UK forests to climate change?

The potential impacts of climate change differ across tree species, geographical locations and timeframes. Climate change is likely to have implications for timber revenues, recreation and woodland landscapes, habitats for plants and animals, biodiversity, regulation of carbon and air pollution. For example, **changes in average temperature, precipitation and soil moisture could potentially cause a fall in the annual potential production of forests in England of up to around 40% by the 2080s** (assuming a high emissions scenario), and **up to around 7% in Wales (relative to no climate change in that year). In Scotland, potential production could be higher by up to around 20%.**

How prepared are forest owners and managers to respond?

In general, this analysis has found that the **adaptive capacity of forest owners and managers is variable across different types of forest owner.** For example, it is **relatively weak among smaller woodland owners,** where forest management generally has a lower priority. However, adaptive capacity is **relatively high over the long-term**[2] **within the larger, well-informed organisations**.

Overall, in the short-term, capacity is lower as the sector cannot change the current distribution and species mix rapidly, owing to very long rotation periods.

To what extent is effective adaptation action expected?

A range of adaptation options are available to forest owners and managers. The groups of options discussed in this report were informed by peer-reviewed and grey literature, and experts.

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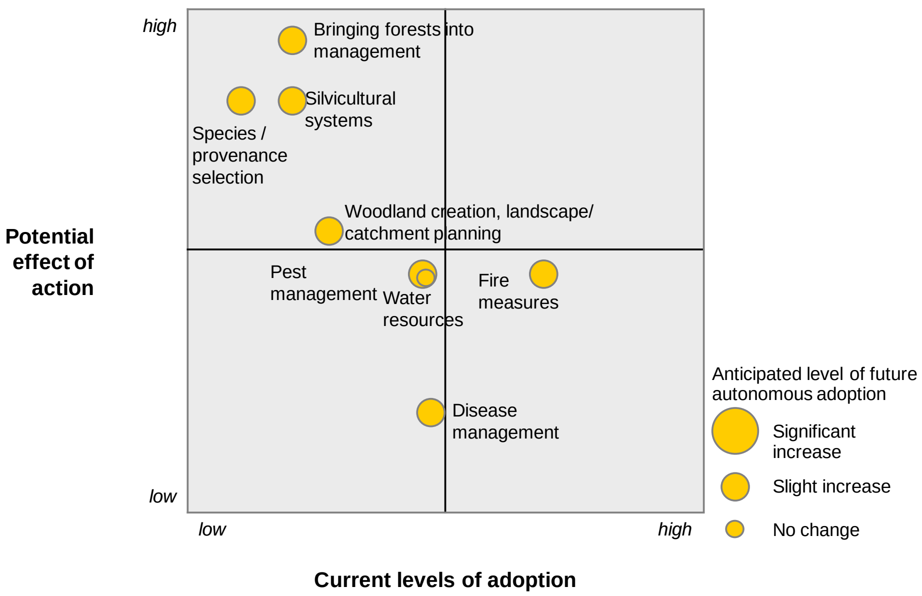
[1] Ecosystem services include provisioning (timber); regulating (carbon sequestration); supporting and cultural (biodiversity, landscape and recreation).

[2] This refers to the life of the tree, considered here to be in excess of around 30 years.

The extent to which actions are likely to be implemented, and their effectiveness, are shown in **Figure 1**. The assessment is based on evidence presented in this report and discussions with experts.

The top right corner of the figure shows those actions where adaptation is working well[3]. Those actions in the top left corner are effective but not widespread (e.g. species/provenance selection, landscape/catchment planning) suggesting that barriers to action exist. The actions in the bottom right corner (e.g. fire measures) are widespread but not always effective, either because they are driven by other things, or they may be easy actions, or they may be maladaptive in some cases. Actions in the bottom left corner are neither effective nor widespread, (e.g. pest disease actions in the context of climate change adaptation are a very low priority given current biosecurity challenges) and are not priority areas to address.

Figure 1: Summary of effects of current and short-term adaptation actions in privately owned woodland



Source: Based on published evidence, stakeholder views and expert advice
Note: Scales are qualitative and relative to the sectors included[4].

[3] There may be areas where the adaptation is maladaptive, but generally and in the short-term, these actions are effective and widespread.

[4] The **current levels of adoption** include forest management decisions that are infrequent (such species selection) to common practices. **Effectiveness** varies from limited scope due to impact of measure, time-frames or effort involved. The position of each measure is based on the classification within main text in this chapter and, given the factors discussed above, could vary considerably depending on type of forest manager

Where actions are in the top-left quadrant - i.e. they are effective but not widely implemented - this indicates the presence of barriers. Likewise, barriers could hinder the effectiveness of those actions in the bottom-right quadrant. It is important to note that even if actions are effective, whether they should be implemented more widely should be subject to a robust analysis of costs and benefits.

Case for intervention

This analysis has highlighted a series of key barriers to effective adaptation and recommends a range of interventions.

Market failures

Externalities can be identified in several forms:

- **Notable proportions of forest are not subject to active management**. In such forests there is little, if any, ability to ensure they are adapted to future climate change. Only 57% (48% in England) of forest and woodland has a management plan or equivalent (Gillam, 2011).
- **Where forests are subject to active management, the incentives for forest managers to protect ecosystem services may be limited by the lack of private return from doing so. Returns may also not be realised within a feasible timeframe, owing to (i) the low activity levels caused by the very long rotation periods (typically 40 to 50 years** and up to hundreds of years for some hardwoods); and (ii) the annual restocking rate of only 0.2% in England (FCE, 2012). The benefits of species or provenance selection actions may therefore take many decades to be realised.

Information failures are evident from a range of perspectives:

- **Forest managers are often not aware of climate-resilient provenances and species to meet long-term timber production needs and ecosystem services delivery**. Availability of climate resilient species and provenances means projected climate change is not consistently reflected in new planting decisions. In addition, there are few climate-resilient tree species presently available from UK nurseries that could out-perform existing species.
- **Little evidence is available on the costs and benefits of adaptation actions** and the conditions under which they are likely to be effective.

/owner. If this diagram were repeated for the Public Forest Estate, the current levels of adoption would be considerably higher, but in many cases the effect of the action may not be substantively different

Policy failures

There are currently **no formal markets**[5] **to allow the economic benefits of enhancing or protecting biodiversity or sequestering carbon, among others, to be realised** by forest owners. Policy addresses this, in part, through grants. However, the current level of grants available is unlikely to be sufficient to increase forest land-cover where land competes with more economically productive uses, such as agriculture.

Behavioural constraint

'Short-sightedness': as noted above, at present commercial managers are considering new species, but most are not planting with a view to climate change.

Governance barriers

Co-ordination barriers: Forest ownership and boundaries straddle the catchment and therefore there are difficulties in co-ordinating actions.

To address these barriers, recommended interventions are:

Recommendations

Recommended intervention

Enhance adaptive capacity by exploring practical and cost-effective ways to **reduce the amount of under-managed woodland.** This should be complemented through the delivery of tailored, practical knowledge and advice to forest managers about appropriate management techniques, and addressing both behavioural barriers and market failures, which mean managers have little incentive better to manage forests (e.g. by creating market mechanisms or grants).

Greater pro-active management of forests is expected to increase resilience in relation to drought, pests and pathogens, and forest fires, as well as other gradual climatic changes. This is because many of the adaptation actions could only be implemented in managed forests (i.e. re-stocking with more resilient species and increasing diversification to reduce the risk of pests and pathogens).

At the stand level, use of smaller coupes for clear-felling and introducing resilient provenances/species could be implemented. Alternatively, effective use of continuous cover forestry to create diverse forest structures could also enhance preparedness of forests to climate change. At the forest-level, active management would better facilitate mitigation of the adverse impacts of fires, pests and

[5] However, less formal payments for carbon sequestration in woodland creation projects can be realised through certification to the Woodland Carbon Code.

pathogens, and/or make the most of potential opportunities (through expanding forest cover with resilient species, for example).

Recommended intervention

Encourage and facilitate through research and demonstration the planting of climate-resilient provenances and species to meet long-term timber production needs and ecosystem services delivery. Ensure timely and tailored information is available to forest owners and managers on the most climate-resilience provenances and species. Information for forest managers must be practical, easily accessible and targeted – this is essential to build adaptive capacity.

Much can be learned from overseas, where climate conditions are similar now to those projected for the UK in the future. However, research would be required to understand their likely performance under current UK conditions. At the same time, the capacity of forestry industry to provide and subsequently process alternative species once they are identified and grown can be increased. This involves raising awareness of the implications for investment in the timber-processing sectors and understanding the future market for timber from these alternative species.

Recommended intervention

Address remaining market failures to support the protection of ecosystem services. Market mechanisms should be explored which facilitate the protection and enhanced delivery of ecosystem services from woodland. The Woodland Carbon Code, the development of the Environment Bank and biodiversity offsets are recent examples.

Recommended intervention

Undertake research and analysis to identify appropriate interventions to facilitate the co-ordination of forest adaptation action between owners at forest/catchment-scale. Implement effective interventions. At the same time, efforts to encourage woodland creation to deliver cross-sectoral benefits (including enhanced resilience to climate change) need to be promoted.

Co-ordination of activity between forest owners could facilitate a number of adaptation actions. For example, it could increase connectivity between forests (thus facilitating gene flow). Co-ordination could also deliver wider benefits for the protection of ecosystem services beyond those available at the forest level.

Recommended intervention

Undertake case study analysis of adaptation actions through robust analysis of the costs and benefits of a range of actions and the conditions under which they are likely to be effective. Adaptive capacity should be built by exploring practical steps to learn from overseas and UK practices to increase resilience. Monitoring, reviewing and sharing of lessons should be carried out.

Long term and/or continuous monitoring and evaluation of the effect of activities at stand, forest and landscape scale would be expected to increase the ability to optimise the value (market and non-market) of forests in the long term.

2 The forestry theme

2.1 Focus of this report

To provide additional evidence relating to climate change adaptation for forestry, this analysis addresses the following question set by government policy officials:

Forestry theme question

Given projected climate change and likely adaptation, what is the case for further intervention in relation to climate change adaptation for forest productivity and associated ecosystem services?

Defra have requested this work focuses on:

- Conifer and broadleaf productivity
- Forestry land-use (including ancient and native woodland) and its contribution to ecosystem service delivery

Assessment of ecosystems services in this report follows the approach taken by the UK National Ecosystem Assessment (UKNEA, 2011), segregating services provided by trees, woodlands and forests into four broad categories:

- Provisioning services - e.g. trees for timber, for bio/woodfuel, agroforestry and wood pasture;
- Regulating services - e.g. climate (carbon sequestration), detoxification (water, air and soil quality regulation), hazard (management of soil erosion and flooding), and habitat for important pests and pathogens;
- Cultural services - e.g. recreation, education, and landscape; and,
- Supporting services - e.g. habitat for pollinators, soil formation, and nutrient and water cycling, and maintaining biodiversity.

Although it is not assessed in detail in this analysis, forests can also contribute to adaptation in other sectors (see below).

Forest management as an adaptation action for other sectors

Adaptation of forestry can be considered from two perspectives. First, the extent to which UK forests are resilient to projected climate change. Second, the role that UK forests can play in supporting adaptation in other sectors. Examples of this second perspective include: planting trees and woodland to provide shade and reduce temperatures in urban areas (see the ECR Report on Residential Housing for more detail); planting forests for slope stability on which infrastructure such as roads and bridges rely (see ECR report on Transport); or, planting on riverbanks to protect rivers from agricultural water run-off (See ECR report on Natural Flood Management).

This study has focused on a selection of ecosystem services based on the availability of reliable evidence, and ensuring a cross-section of different services is considered. The focus of this report is on the most common timber species as assessed in the UK Climate Change Risk Assessment (CCRA: Moffat *et al.,* 2012). Ecosystem services not covered in this report include soil formation, air quality and those provided by urban forests. Energy crops (e.g. short rotation coppice), are also not considered.

2.2 Approach

This report presents the results of extensive stakeholder engagement along with a wide range of published evidence and new analysis. The work was advised by experts from Forest Research and John Murlis (former Chief Scientist at the Environment Agency).

2.2.1 Stakeholder engagement

The team conducted 21 interviews with stakeholders alongside receiving on-going guidance from expert advisors. Stakeholders are listed in Annex 1 and include researchers, academics, trade associations, sector specialists, public and private forest owners, forest managers and policy makers. Their views form an essential part of the evidence base. As the interviews were conducted under Chatham House Rules, stakeholders are not referred to individually or by name.

Two focus groups were also held to test emerging findings. The first involved representatives from the Forestry Commission and Forest Research, and the second involved stakeholders from the NGOs (e.g. Sylva, Woodland Trust), private forest management industry, forestry experts in Devolved Administrations (DAs), research organisations and Natural England.

2.2.2 Analysis

The framework for analysis to address the question involves a series of steps.

- **Understanding the scale of the challenge:** this involves exploring the evidence on the current scale of risks posed by climate change (including extreme weather events) and understanding the potential magnitude of impacts these give rise to.

- **Understanding the context in which adaptation is considered:** this includes identifying the relevant actors and their adaptive capacity as well as identifying relevant policies that are likely to facilitate or hinder effective adaptation.

- **Identifying and assessing adaptation actions currently being implemented by some in the sector, considering their adoption and relative effectiveness.** These actions include building adaptive capacity and implementing action to limit damage or make the most of an opportunity. Barriers are then identified in terms of where uptake or effectiveness (or both) are constrained. Barriers are explored in the following categories:
  - **Market failures:** the degree to which there are market failures relating to pricing signals; externalities[6]; public goods; and where information may not be timely, accurate, relevant or is incomplete;
  - **Policy:** the framework of regulation and policy incentives;
  - **Governance:** institutional decision-making processes; and,
  - **Behavioural:** for example, 'short-sightedness' and willingness to act.

The case for intervention to address those barriers is then explored through the consideration of adaptive management and illustration of 'what-if?' scenario analysis.

The quantitative and qualitative analysis presented differs to that of the UK CCRA (Moffat *et al.,* 2012) recognising the specific question asked of this report. Within the time and scope of this report, it has not been possible to model the wide range of impacts of projected climate change on UK forests under a full range of projected future climate change scenarios. Instead, illustrative 'what if?' scenarios are presented in Section 6.

2.2.3 Uncertainties and limitations

Understanding the economics of adaptation is a complex process. There are many challenges defining the context within which this work is carried out. First, **time-frames being considered are long**. This report looks to the 2080s so

[6] Where there are costs or benefits imposed on others that are not accounted for in individual decision-making.

there are uncertainties in the potential impacts of climate change on UK forests and associated ecosystem services (see Annex 2 for further discussion of climate change uncertainty). These uncertainties are explained within the report.

Second, **analysis must work with currently available information** – in some areas, there are substantial gaps (as will be noted). Although significant advances have been made in recent years, for example through the development of detailed UK Climate Projections in 2009 (UKCP09) and the recently published UK CCRA (Moffat *et al.,* 2012), adaptation economics is a developing field of analysis. It will be important to update and monitor analysis over time to ensure practices remain current and guided by the best available evidence. Challenges in the analysis include:

Data availability for projections of forest potential production: Given the two-month time-period for this project, the data used in the analysis was based on the published National Forest Inventory (the version available at the time of writing). Forest Research is planning to develop more detailed analysis of future timber forecasts but, at the time of writing this report, that work has not been completed.

Interaction across measures: The adaptation measures discussed in this report do not occur in isolation. For example, approaches for managing pests and pathogens are strongly influenced by silviculture methods. Similarly, activities at a stand or forest level are closely related to landscape-level interventions.

Available evidence: Assessing the extent of adaptation measures and their likelihood of increasing in the future is based on available evidence. Owing to the absence of evaluation of adaptation methods, in some cases assessments are by necessity subjective as advised by experts and wider stakeholders (this is noted where this is the case). There are a number of areas where there are substantial differences of opinion regarding the role of different measures (e.g. clear-felling versus continuous cover forestry systems). Furthermore, the evidence base associated with activities of smaller forest owners is not as comprehensive as land managed by larger organisations.

Comprehensiveness: Although every effort has been made to cover the key aspects of prospective adaptation actions, analysis is constrained by the accuracy of published information and the expertise of the particular experts and stakeholders that responded to the work. Given the diversity of forests across the UK some generalisations are inevitable.

Aggregating impacts: This work assesses the scale of the projected climate change and associated adaptation actions across the UK. Many of these impacts, and the responses to them, are expected to impose costs that, although high at a local level, could be relatively lower when considered at a national level.

Many factors influence the potential impacts of climate change. This report uses UKCP09 and UKCIP02 projections along with evidence in the CCRA (Moffat *et* *al.,* 2012) and other published sources. The key area where this report differs in the analytical approach to the CCRA is in relation to the extension of potential forest production projections from forest managed by the Forestry Commission (in England, Scotland and Wales) only, to illustratively also cover private forests. This is undertaken using the most recent National Forest Inventory (2011, with 2012 updates), which provides information not available at the time the CCRA (Moffat *et al.,* 2012) was published.

2.3 Structure of this report

This report is structured as follows:

Section 3 describes the scale of the challenge of projected climate change for UK forests.

Section 4 presents the context for adaptation, including the adaptive capacity of forest owners and managers.

Section 5 explores the range of adaptation actions that could form part of an effective adaptation strategy, along with the key barriers to their implementation.

Section 6 presents the case for intervention including a discussion of adaptive management (illustrated though adaptation roadmaps) and 'what if?' scenarios.

3 Scale of the challenge

Key messages

This sector is characterised by a range of factors. Trees have long rotations, with typical cycles of 40 to 50 years, (up to hundreds of years for some hardwoods), and an annual restocking rate of only 0.2% in England. Ownership is fragmented and there is a high proportion of non- or under-managed woodland. Although timber is a traded commodity, evidence suggests that the value of forests in providing ecosystem services, including carbon sequestration and recreation, is higher than the timber itself.

Evidence suggests key threats and opportunities likely to affect the sector are: decreased soil moisture (threat); higher temperatures (opportunity/threat); increased CO_2 concentrations (opportunity); new pests and pathogens (threat); increased activity of existing pests and pathogens in terms of longer active periods and wider scale of impacts, and extreme weather events (such as drought and windstorms: threat). Forest fire risk could also increase.

Timber yield projections illustrate variability across species and geographical areas. In the long-term, climate change is expected to impact on the yields of different species differently, depending on location. Under a high emissions scenario, the analysis indicates by the 2080s, a projected increase in potential production of up to 20% in Scotland, a fall of up to 7% in Wales and a fall of around 40% in England. (Assumptions and calculations are set out in Annex 3).

In the absence of further adaptation measures being implemented, and despite improvements in tree growth in some locations, climate change could result in an estimated net gain in potential production across UK forests of about £5 million annually in the 2050s, and a net loss of up to £108 million annually in the 2080s (relative to no climate change). Carbon sequestration benefits could be in the region of £87 million annually in the 2050s, but result in a net loss of up to £1.8 billion annually by the 2080s. The projections differ across the Devolved Administrations with potential production of forests in Scotland perhaps increasing as a result of climate change to the 2050s.

3.1 Introduction

This Section explains the structure of the sector, the key actors involved, and their behaviour and incentives. Each of these directly influences the assessment of adaptive capacity in Section 4. The scale of potential climate effects is also discussed, assuming no further adaptation actions. This sets the baseline against which the effectiveness of adaptation actions can be assessed later in the report.

3.2 Brief introduction to the sector

UK forests cover 3 million hectares, 13% of the UK total land area (Forestry Statistics, 2011). Forestry is a multifunctional sector. In England, 40% of annual wood production is harvested for timber and fuel (Atkinson and Townsend, 2011). 23% of woodland is managed for recreational activities. Smaller proportions of woodland are used predominately for woodland and wildlife conservation. Approximately 13% is managed in this way, with 7% of woodland protected under designations for biodiversity. About 18% of UK forests are classed as ancient woodland (including plantations of non-native species on ancient woodland sites: Atkinson and Townsend (2011). There is a proportion of land which is not actively managed; in some cases it is held for hobby ownership only.

UK forests provide a number of key market and non-market ecosystem services (UKNEA, 2011). These fall broadly into four key categories i) provisioning services (e.g. fuel and fibre); ii) regulating services (e.g. climate, flood hazard, noise reduction, air quality); iii) supporting services (e.g. water cycling, oxygen production and biodiversity); iv) cultural services (e.g. heritage, amenity, health and recreation).

Annual turnover of the timber industry is £7.6 billion (BIS, 2011)[7], which ranks the wood industry and forestry as fifth out of 120 major industries in the UK. Forestry itself employs around 14,000 workers in the UK (Atkinson and Townsend, 2011). Sustaining a domestic industry will be important in a global market where 70% of all timber is sourced from only 7% of forests (Atkinson and Townsend, 2011).

The rotation periods of forests in the UK can range between three years for short rotation coppice, 40-50 years for softwood, to hundreds of years for some hardwoods. Approximately 0.2% of forest is harvested (in England) and restocked each year. Sitka spruce is the most common tree species in Britain (accounting for approximately half of total standing coniferous volume) and accounts for the largest volume of growing stock (170 million m^3 in 2011), followed by Scots pine (50.6 million m^3 in 2011: Forestry Commission, 2012a); oak accounts for 28.7 million m^3 (in 2010: Moffat *et al.,* 2012).

Currently a large proportion of timber plus wood products consumed in the UK are imported (more than 80% in 2010: Forestry Statistics, 2011) mainly from Scandinavia and the Baltic States, which are likely to maintain productivity under future climate change conditions. There have not been strong financial incentives to maximise timber production in the UK and this context has allowed

[7] This includes annual turnover classified by the SIC industry codes for forestry and logging; and the manufacture of wood and products of wood and cork, except furniture and the manufacture of articles of straw and plaiting materials

biodiversity conservation and other non-market objectives to receive a relatively high priority for land-owners (Mitchell *et al.,* 2007). Biodiversity conservation is an important service of forestry, maintaining tree species diversity and providing habitats for insects, birds, other invertebrate and vertebrate animals, plants and microbes. An annual value of UK forests for biodiversity has been assessed as £476 million (UKNEA, 2011).

Estimates of the value of carbon sequestration by the UK Natural Ecosystems Assessment (Valatin & Starling, 2010) suggest that **UK woodlands' carbon value could be around twice the value for timber production**. Estimates of a mean annual value per hectare of £239[8] are more than double the mean value of softwood timber (based on 2009 values). The carbon value of woodland can be realised in new woodland planting schemes through certification to the Woodland Carbon Code and entering into an agreement with a (private) source of funding, generally on an *ad hoc* basis. However, the lack of formal trading market for such ecosystem services (i.e. carbon sequestration) means that potential benefits from enhancing resilience to climate change are not likely to be realised by forest owners.

Recreation and landscape are important cultural services provided by woodland and have been valued for the UK at £484 million each year (UKNEA, 2011). Approximately 52% of woodland is open to visitors, with over 389 million visitors each year, peaking in the summer period (Forestry Statistics, 2011).

Maintaining heritage is another service provided by ancient woodland. 18% of woodland is classified as ancient woodland (i.e. continuously wooded since AD 1600, or AD 1750) in Scotland; it provides an important role in maintaining biodiversity. This figure includes 223,000 ha of Plantations on Ancient Woodland Sites and 645,000 ha of ancient semi-natural woodland (Forestry Statistics, 2011).

Owners of woodland can be broadly segmented into six groups i) public forest owners; ii) large commercial owners; iii) large mixed estates held for commercial or other reasons; iv) farm woodland and small woodland holders; v) non-landowning and hobby ownership; vi) land held by charities or others for biodiversity or other reasons.

More than 50% of British woodland is owned by individuals or families with an estimated 100,000 woodland holdings[9]. The single largest owner is the Forestry Commission/Forest Service of Northern Ireland, which owns (on behalf of the government) 870,000 ha out of the total of over 3 million ha (Forestry Commission, 2011). Only 57% (48% in England) of forest and woodland has a management plan or equivalent (Gillam, 2011), which indicates the remainder is

[8] Based on central Department of Energy and Climate Change (DECC) non-traded values of carbon.

[9]http://www.forestry.gov.uk/pdf/soefind6.1.pdf/$FILE/soefind6.1.pdf

less likely to be actively managed or engaged with the advice and methods advocated by the Forestry Commission.

Despite fragmented ownership, commercial managers may manage a number of forests on behalf of many owners. The largest private forest management business is UPM Tillhill, which manages 200,000 hectares. Charity groups such as the National Trust and Woodland Trust hold and manage 20,000 ha and 25,000 ha, respectively (Moffat *et al.,* 2012). In the timber industry, the owners of wood-processing businesses (and other businesses along the timber supply chain) are not usually also the owners and managers of forest and woodland. The Forestry Commission undertakes or commissions much of the research in the industry and is seen by the private sector as the leader in best practice.

The distribution of woodland, ownership and ecosystems service valuation across England and the Devolved Administrations are shown in **Table 1.**

Table 1. Distribution of woodland, ownership and ecosystems services valuation across England and the Devolved Administrations.

	Conifers (thousand ha)	Of which Sitka spruce	Broadleaf (thousand ha)	Proportion of public ownership	Annual value of non-market ecosystem services*	Ancient woodland (thousand ha)
England	411	19.5%	886	16.5%	£1,090m	341
Scotland	1081	48.8%	309	34.6%	£128m	148
Wales	167	50.3%	137	37.5%	£42m	61
Northern Ireland	66		22	69.3%		1

Sourced from the Forestry Commission inventory, (Forestry Commission, 2011e)

*Value from Willis *et al*., (2003) includes recreation, landscape, biodiversity and carbon sequestration, as used by the UKNEA (at 2010 prices), using the allocation across countries presented in Snowdon (2011)

3.3 Approach used for the analysis

The impacts of climate change on conifers and broadleaves are considered separately, and then combined to provide a UK-wide picture. Forests can be formed of a number of possible species and provenances. Due to data availability, this analysis is based on potential production (the proxy used here for productivity) and land-cover for six common broadleaf species and eight common conifer species[10]. This is also the approach used in the CCRA (Moffat *et al.,* 2012). Results are then combined and presented as overall impacts, with results presented for England and each DA.

Table 2 sets out an overview of some of the key assumptions on which the analysis is based; further detail on each is given in Annex 3.

[10] Broadleaf species include: ash, beech, pedunculate oak, silver birch, sycamore, and sweet chestnut. Conifer species include: Corsican pine, lodge-pole pine, Scots pine, Sitka spruce, Norway spruce, Japanese larch, European larch, and Douglas fir.

Table 2. Core assumptions underpinning the analysis

	Conifer	Broadleaf	Total
Current land area (million hectares)	1.7	1.4	3.1
Restock rate in 2011 (ha per year)			14,000
New planting in 2011 (ha per year)			8,200
Deforestation in 2010 (ha per year)			1,410
Aspirational[11] annual forest cover growth of all countries combined (ha/year) based on announcements made over the last six years			17,350
Average yield	11 (ranging between 4 and 18)	6 (ranging between 2 and 8)	n/a
Based on yield classes (i.e. maximum mean annual stem volume increment over a rotation) for individual species, assuming an even age-distribution.			
Market price for timber	£10.75 – £21.5 per m^3 overbark	£21.5 - £43 hardwood assumed to be twice that of softwood as market price information is limited in comparison with softwoods*	Price identified by Forestry Commission as an average of prices over (2007-2011) - private sector experts see private sales achieve twice this level
Average carbon density by species (tCO_2 m^{-3})	0.605-0.825	0.97-1.025	
Value of non-traded carbon dioxide £/tCO_2)	56 in 2011; 212 in 2050; 324 in 2080 (central values)		

***estimated within Moffat et al., 2012**

ECR analysis of potential annual volume increment of UK forests is defined as the product of average yield class and area for individual species within the UK. Yield classes were derived using the Ecological Site Classification decision support system and represent the average rate of volume production (in cubic meters of timber per hectare per year) over the course of a rotation). Restocking rates for 2011, as reported in

[11] Land-cover aspirations noted in the UK Forestry Standard Forests and Climate Change Guidelines (2011) include: increasing woodland cover in England from 10% to 13% by 2060 (Natural Environment White Paper, 2011); increase forest cover in Scotland by 10,000 hectares per year from 2012-2022 (Scottish Executive, 2006); create 100,000 hectares of new woodland in Wales between 2010 and 2030 (Ministerial announcement, 2010); and increasing forest cover in Northern Ireland from 6% to 12% from 2006 to 2056 (Northern Ireland Forestry(2006).

Forestry Facts and Figures (FC, 2012), are assumed.

The rest of this Section illustrates the potential impact of climate change on conifer and broadleaf species across the UK, drawing largely on the work of the CCRA (Moffat *et al.*, 2012), complemented by other sources where appropriate.

3.4 Key biophysical drivers of forest productivity

There are several factors that drive forest productivity. Many are directly climate related, or are factors which themselves are subject to the impacts of climate change and, thus, indirectly affect productivity. Direct and indirect biophysical drivers include:

Nutrients, water and pollution: macro- and micro-nutrients, soil moisture (which can also affect depth of root growth), atmospheric concentration of carbon dioxide and pollutants, such as ozone, oxides of nitrogen and sulphur dioxide;

Climate: temperature (including extremes of high and low temperature), solar radiation (both duration and intensity), rainfall and snowfall (amount and intensity), windiness and severe storms;

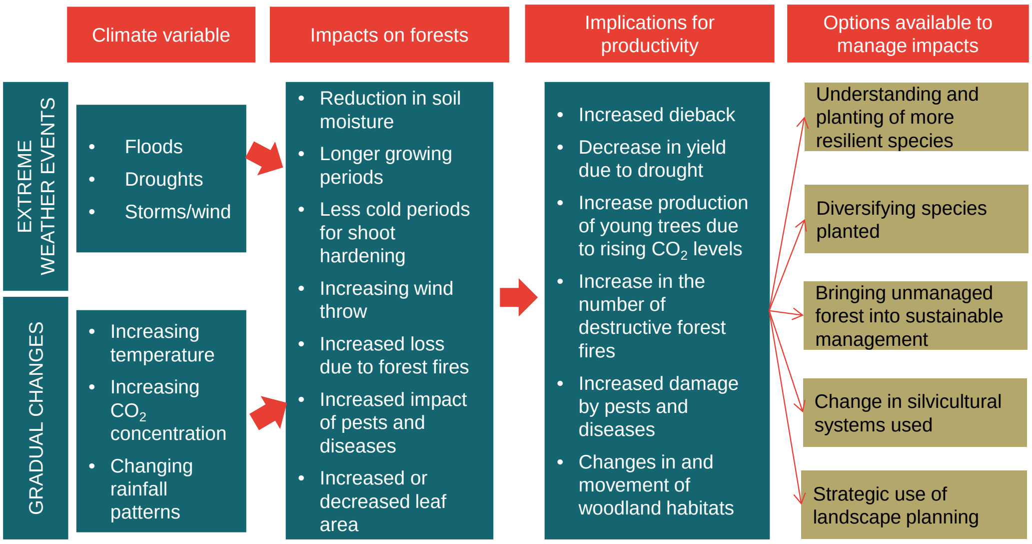
Pests and pathogens: emergence and introduction of new species or strains and changing distributions and activity of existing pests and pathogens; and,

Land: its geographical location, geology, relief, aspect and soil type.

3.5 Projected climate change impacts on forest productivity

Figure 2 provides an overview of the key projected climate change impacts on forests to the 2080s.

Figure 2. Simplified illustration of impacts of climate change on forestry productivity and examples of adaptation measures for forest management



Climate change is projected to impact on forestry, both through long-term trends in climate variables, such as average temperature and precipitation, and through the increasing frequency of more extreme weather events, such as drought and/or flooding. In addition, climate change indirectly impacts forests, as it affects the viability, life-cycles and activity of pests and pathogens which in turn damage forests.

The CCRA (Moffat *et al.,* 2012) scores 19[12] climate change effects on forests for their expected economic, environmental and social impact, along with their impact on vulnerable groups, likelihood of occurrence and the urgency of need for action. The results of this identified the following top three areas:

1. Increase in variety and activity of pests and pathogens.
2. Drought damage.
3. Change in tree species suitability due to the projected impacts of long term climate change.

These form the focus of the quantitative analysis in this report.

Key climate change variables identified by the CCRA (Moffat *et al.,* 2012) include:

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[12] These included: pests and diseases, drought damage, change in climate suitability for species, biodiversity loss, waterlogging, change in soil organic carbon, snow and frost damage, wind throw, fires, erosion and landslips, CO_2 fertilisation, saline incursion, emission of volatile compounds, winter hardening, oxidation of peatlands, weed species, invasive flora and fauna, increased tourism, growing season for nursery stock.

Increased summer temperatures[13] **and reduced rainfall**[14]**:** These are expected to lengthen growing periods, but also increase periods of drought stress, particularly in the southeast of England.

Increased damage by pest and pathogens as a result of increasing temperatures: Warmer temperatures are expected to encourage the survival and activity of many current pests and pathogens (although some may decline: Straw, 1995 cited in CCRA: Moffat *et al.,* 2012). They could also favour invasive species, creating environments in which current pests and pathogens found in Europe or elsewhere thrive in the UK. For many pests and pathogens, future trends remain poorly evaluated. However, in some cases expert judgement allows some assessment to be made of the changes in their prevalence (Broadmeadow *et al.,* 2009b, cited in CCRA: Moffat *et al.,* 2012). In affected forests, pests and pathogens could cause a substantial reduction of productivity or timber quality, and even lead to tree mortality.

Rising CO_2 levels: Current concentrations of CO_2 are not optimum for photosynthesis (Broadmeadow and Ray 2005). Increased atmospheric CO_2 concentrations[15] are therefore expected to increase yield, although the magnitude of the impact is uncertain as a result of physiological feedbacks on tissue nutrient concentrations, leaf area, respiration and soil mineralisation.

Increased wind: Projected changes of wind remain uncertain[16]; combined with the uncertainty of the impacts of climate change (e.g. on root growth, which affects tree stability), this report is unable to identify the extent of potential future impacts associated with wind.

[13] Climate change projections include an increase in mean summer temperature. By the 2050s, for the central estimate (p50) of the UKCP09 medium emissions scenario, the southern part of England could see mean temperature rises of between 2.3 °C and 2.7°C (Murphy *et al.,* 2009). The projected summer minimum mean air temperature over the whole UK ranges from 0.8 °C in the p10 low emissions scenario to 5.7 °C in the p90 high emissions scenario for the 2050s (UKCP09). Mean temperature increases will vary regionally.

[14] Mean winter precipitation is projected to increase by 9-17%[14] in the 2050s relative to the 1961-1990 baseline, depending on location. However, the spread in projections is wide, ranging from -2% for the lower bound of the UKCP09[14] low emissions scenario in Scotland East, to +41% for the upper bound high emissions scenario in South West England. Summer rainfall is projected to decrease. There is a general south to north gradient, with changes between -20% and -50% in the southwest of England, to changes of -10% to +10% in Shetland across the p10 low emissions and p90 high emissions scenarios (Murphy *et al.,* 2009).

[15] The annual mean atmospheric CO_2 concentration for 2010 was 390 parts per million (ppm) and is projected to rise by another 90-160 ppm by the 2050s (IPCC, 2007).

[16] Recent research has suggested that "there is no consistent signal of change in either storms or blocking near the UK in either the ensemble of Met Office models or the ensemble of alternative models. Such changes as are seen are relatively modest, and the potential for substantial changes appears to be small" (Source: Murphy *et al.,* 2009).

Drought: The metric for drought impacts on productivity used in this study is soil moisture deficit[17]. This is projected to increase, and can cause stem-cracking in susceptible trees (Green and Ray, 2009, cited in CCRA: Moffat *et al.,* 2012), which makes the timber unsuitable for structural use. It can also cause tree mortality, usually in combination with other stresses such as pests and pathogen outbreaks (Green and Ray, 2009, cited in CCRA: Moffat *et al.,* 2012), although this is not taken into account in the projections.

Forest fires as an indirect impact of extreme droughts: An increase in the frequency or severity of droughts would be expected to lead to an increase in the conditions which promote wildfires, with a projected increase from 10% in the north to 50% in the south by the 2080s[18] (from Met Office McArthur Forest Fire Danger Index in CCRA: Moffat *et al.,* 2012). The impact of drought on wildfire frequency and severity is dependent on the age structure of the forest and is therefore difficult to quantify. Separating these effects creates uncertainty around forecasts of impact on productivity.

Climate change is projected to impact both the growth rate and mortality of forests (i.e. productivity[19]) and hence potential timber production.

The following explains the analysis undertaken to provide an indicative estimate of the impact of climate change on potential timber production of the UK forestry resource.

3.6 Forest productivity projections in the absence of climate change

Timber productivity – described here as potential production – is not necessarily what will be harvested from the forest; here it is estimated as annual growth of stems (irrespective of whether the wood is harvested or not). It is estimated for each tree species as the product of area covered by a particular species (hectares of forest) and the species-specific yield class, which is the maximum mean rate of volume production (in cubic meters of timber per hectare per year) over the course of a rotation. The approach compares potential production under future climate scenarios, assuming no further adaptation actions are taken. More accurate projections would require more complex modelling that was not feasible within the time-frame available for this study.

[17] Soil moisture deficit is the amount of water needed to bring soil moisture back to field capacity, where field capacity is the amount of water a well-wetted, but freely drained soil can hold.

[18] Change in wildfire risk from 1980 to the 2080s, in annual mean values.

[19] Tree mortality, for example under extreme events, is assessed as a reduction in production. It has been calculated in the CCRA as an impact on yields of those species affected.

The direct impact of climate change, as a result of temperature and soil moisture changes, was assessed in the CCRA (Moffat *et al.,* 2012) using the Ecological Site Classification (ESC) tool developed by Forest Research. The CCRA (Moffat *et al.,* 2012) used this tool to assess the current and projected potential yield of 14 different species in 15 different regions of the UK, but was restricted to the public estate[20]. This analysis extends the CCRA (Moffat *et al.,* 2012) analysis to combine the impact on yields with the most recent inventories of public and private tree coverage across the UK by species. This leads to a base-case potential forest production, (i.e. one without the effects of projected climate change). The methodology is set out in Annex 3.

Moffat *et al.,* (2012) used yield class as a measure of potential timber production. As noted above, yield class is defined as the maximum mean annual growth rate of a stand of trees over the course of a rotation (in units of cubic metres per hectare per year. Therefore, the projections of potential production in this report would be representative of ideally managed woodland areas (harvested at the time of maximum mean annual growth increment) with a normal age distribution for the whole woodland area. The baseline values therefore exceed the current actual production figures considerably. Harvest of UK softwood and hardwood in 2010 was estimated by the Forestry Commission to have been 10.5 million m^3 but annual forest growth increment is approximately 21 million m^3, exceeding harvest by a factor of approximately 2 (2010 figures from FC sustainability indicators[21]). Therefore, although the figure of 25 million m^3/yr given in this report for the baseline situation (for a limited number of tree species[22]) over-estimates production (i.e. potential production), it is not inconsistent with published figures of annual increment[23].

To reflect the range of uncertainties, alternative assumptions have been used: for example, **Figure 3** combines yield class impacts and different amounts of forest land-cover. All countries in the UK have published aspirations for increases in forest cover, with an outlook to the mid-century[24]. **Figure 3** shows potential

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21 http://www.forestry.gov.uk/forestry/ahen-5hzcxz

22 This analysis used data on 6 key broadleaf species and 8 key conifer species, and known hectares of forest (see Annex 3). 85% of current woodland in Great Britain is represented by the species illustrated (Forestry Statistics, 2011).

23 The Forestry Commission estimates UK softwood production in 2012 will be 10(i) million m^3, and annual standing conifer forest growth increment to be 15 million m^3 (excluding Northern Ireland)(ii), therefore the 16 million m^3 estimated in this report overestimates softwood production by approximately 7%. (i) Forestry Facts and Figures 2012 http://www.forestry.gov.uk/pdf/FCFS212.pdf/$FILE/FCFS212.pdf (ii) Annually for the years between 2012-16. http://www.forestry.gov.uk/forestry/infd-8rce4s 2011 forecast - 25-year forecast of standing coniferous volume and increment

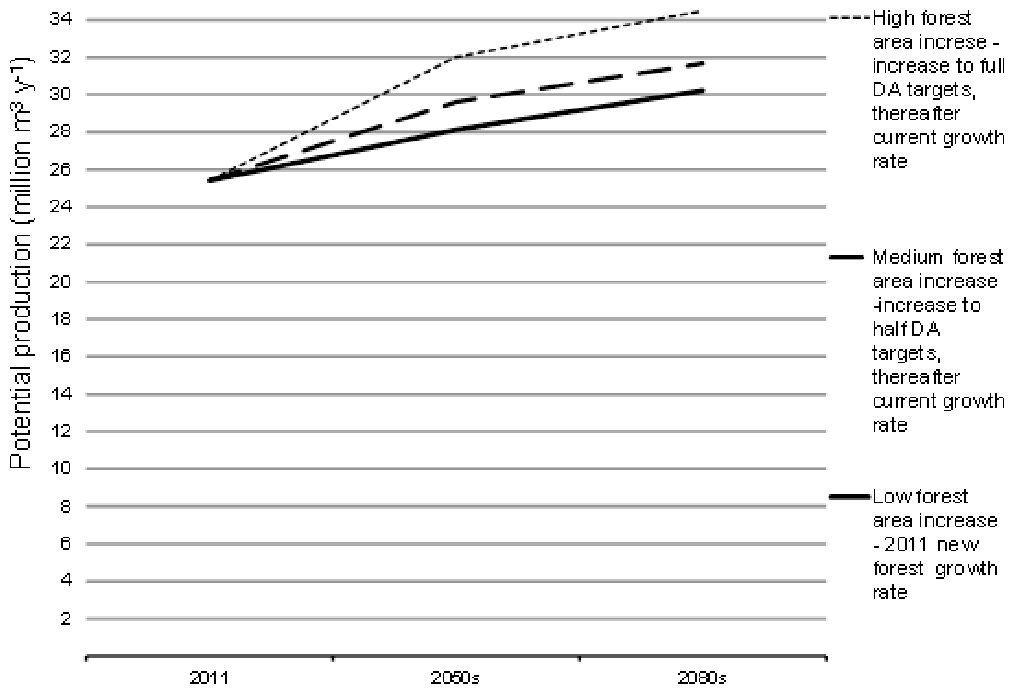
24 Those noted in the UK Forestry Standard Guidelines (2011) include; illustrative scenario of increasing woodland cover in England from 10% to 13% by 2060 (Natural Environment White Paper (2011)); increase forest cover in Scotland by 10,000 hectares per year from 2012-2022 (Scottish Forestry Strategy (2006));

forest production to increase between 11% and 26% by the 2050s depending on the increases in land-cover assumed[25], net of deforestation (based on 2010 levels). The baseline applies 2011 levels of new planting for each DA provided in Forestry Statistics (2011).

create 100 000 hectares of new woodland in Wales between 2010 and 2030 (Ministerial announcement (2010)); and increasing forest cover in Northern Ireland from 6% to 12% from 2006 to 2056 (Northern Ireland Forestry: a strategy for sustainability and growth, 2006).

25 Note that yield class projections are used for the 2050s and 2080s using the ESC model. The area of forest cover is estimated on the basis of the aspired/illustrative future forest cover scenarios announced by each of the countries of the UK. This has been estimated for the years 2050 and 2080 based on those aspirations.

Figure 3. Base-case projections of potential production of UK forests in 2011, the 2050s and 2080s, without the effects of climate change.



Sources: ESC model yield class (which represents maximum average rate of volume production (since planting/regeneration) per hectare of forest (in cubic meters of timber); and forestry inventory data are used for restocking rates in 2011. Depending on the age structure and diversity of management regimes of UK forests in the 2050s, the projections within this chart could be as much as two thirds lower. Other sources include: distribution of species in 1999 (National Inventory of Woodland and Trees, Forestry Commission), Forest Facts and Figures 2011 (Forestry Commission, 2011); hectares by country and Forestry standards and guidelines recording forest cover aspirations/illustrative scenarios by individual countries announced between 2006 and 2011

3.6.1 Value of forest production including the provision of ecosystem services

The economic (social and market) value of forest production relates to the 'provisioning' ecosystem services it provides. Further ecosystem services derive from the forest stock itself.

The increase in potential production provides a direct estimate of the value of potential **provisioning** services in the form of timber provision. This will only represent an 'option' value, as not all production would be harvested (i.e. forest owners have the option to harvest their trees for timber but may choose not to). Multiplying the potential production by average market values (see Annex 3) provides an estimate of the potential value of the provisioning services of forestry. This report does not consider other dependent provisioning services such as venison supply, nor does it include any alternative values for timber, such as when used as firewood.

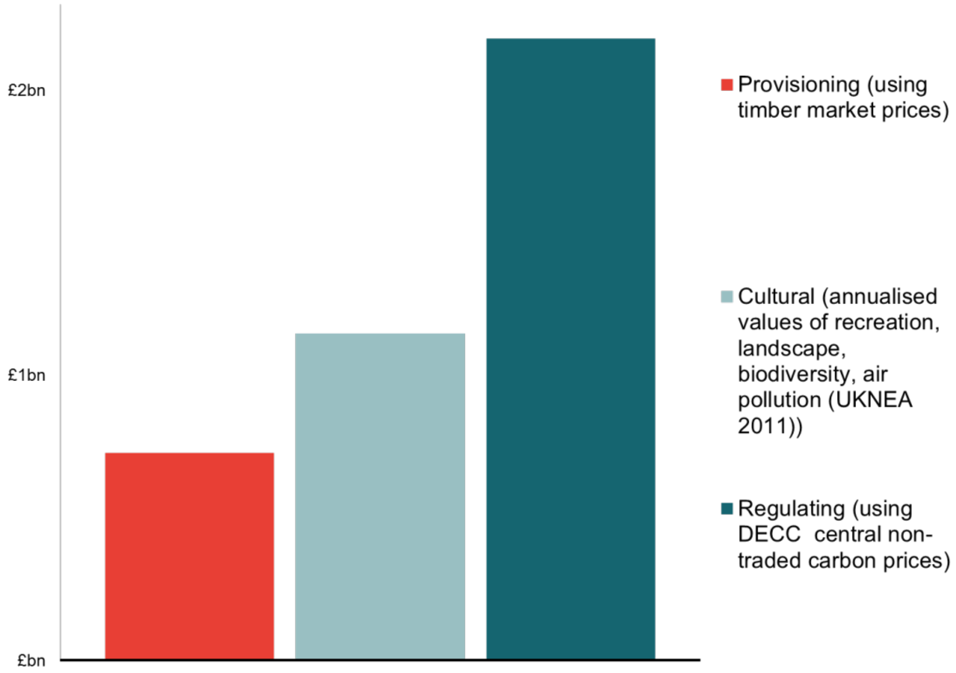
Forests also provide **regulating** services in the form of carbon sequestration[26], and water regulation (Nisbet *et al.,* 2011). The quantity of carbon dioxide absorbed from the atmosphere will be dependent on the area, age and nature of the forest. Within the time-frame available for this report, it has only been possible to provide a provisional estimate of carbon uptake. CO_2 sequestered has been valued using the DECC central estimates for non-traded carbon. These have been combined with species-specific carbon densities, adjusted to account for non-timber components (see Morison *et al.,* 2012). Annex 3 provides further details and limitations of the analysis. This report is restricted to annual rates of carbon uptake and does not consider total carbon stocks.

Carbon sequestered by forest soils could also be considered. In many areas, increased temperature and CO_2 concentrations will increase the rate of sequestration by vegetation (except where drought limits growth), but this is likely to be balanced by increased rates of soil respiration in the short to medium term. In the long-term, for old growth forest (i.e. woodland in long-term equilibrium), it has been claimed that the increased rates of soil carbon loss could outweigh the sequestration by vegetation, and the terrestrial biosphere will become a net carbon emitter (Cox *et al.,* 2000). Due to the high level of uncertainty associated with soil carbon dynamics, the value of soil carbon sequestration is not considered in this analysis.

Forests also provide supporting and cultural services. This report has not identified the full value of these services. Some of these services have, however, been valued in the UKNEA (2011) using a 'willingness to pay' assessment and including values for recreation, biodiversity and landscape. Figure 4 summarises the estimated value of current ecosystem services.

[26] Other regulating services have not been assessed within this report, many of which are dependent on location, so their value may not have been fully captured by a review at national level. However, they should be considered within a more complete cost benefit analysis of adaptation measures. Such services could include: the prevention of soil erosion, flood alleviation, reduction of agricultural diffuse pollution, and maintenance of lower watercourse temperatures.

Figure 4. Undiscounted estimates (as assessed above) of value of current UK forest production without further climate change (current prices)*



*This is an indicative scenario based on yield class (which represent maximum average rate of volume production (where average means 'since planting/regeneration') per hectare of forest (in cubic meters of timber). Depending on the age and management structure of UK forests in 2080 the value of these ranges could be as much as two thirds lower. Timber values are assumed to be at the upper bound of the assumption range in Table 2. The annualised value of carbon stores in the existing forest stock is not included within the 'regulating services' bar, only carbon sequestered by the yield within that year is shown. The value of stored carbon (assumed to be at the central value of Table 2) is likely to be much greater. About 150 MtC is currently stored in trees, plus about 640 MtC in forest soils - total stored is therefore 790 MtC (2,900 MtCO2e: Read *et al.,* 2009).

The non-market values of forest production are estimated to be much greater than those of timber.

The value of forests, and the extent to which that value is recognised in market activities, is likely to affect the amount of adaptation action that is taken by the private sector. This disparity between the market values and the much higher non-market values is important.

There are, however, many forests managed by the Forestry Commission or other charities and organisations which have objectives for managing biodiversity, recreation and landscapes.

3.7 Projected impact of climate change on potential production of UK forests

This assessment quantifies the projected impact of two climate variables using the methodology adopted in the CCRA (Moffat *et al.,* 2012):

- Impacts of temperature and soil moisture on the suitability of the climate for different species; and,
- Increased impacts of drought[27].

Further descriptions of these measures and results are presented in Annex 3.

There are a number of ways climate change is projected to impact forest productivity and the ecosystem services it provides. Many are complex and have not yet been reliably measured at a UK-wide scale. As noted above, Moffat *et al.,* (2012) assessed 19 different climate change impacts. Included within these is increased activity of pests and pathogens. The scale of impact will be dependent on the identity of the pest/pathogen and the severity of the outbreak. Illustrative examples are described further in Section 6.

Figure 5 shows the projected impacts of climate change on UK potential forest production in the absence of further adaptation in the 2050s and 2080s. Projections are shown in relation to the impacts of average temperature and precipitation (top chart) and drought (lower chart).

As noted above ESC modelling uses the high emissions scenario to estimate the impact of climate change on species yield. This is consistent with the CCRA analysis (Moffat *et al.,* 2012).

Given uncertainty over future forest cover, the range outlined by the box represents high and low scenarios of future increases in forest cover.

The red box represents projected potential production in the 2050s and 2080s, assuming current climate.

The green box represents potential production with climate change under a high emissions climate scenario. The solid line represents the production for mid-range scenario of woodland expansion. The full ranges outlined by the arrows show high and low future increases in forest cover.

[27] The definition used here is the same as the CCRA (Moffat *et al.,* 2012), which "excludes the positive effects of mild drought".

Figure 5. Projected impact of climate change on UK potential forest production in the 2050s and 2080s

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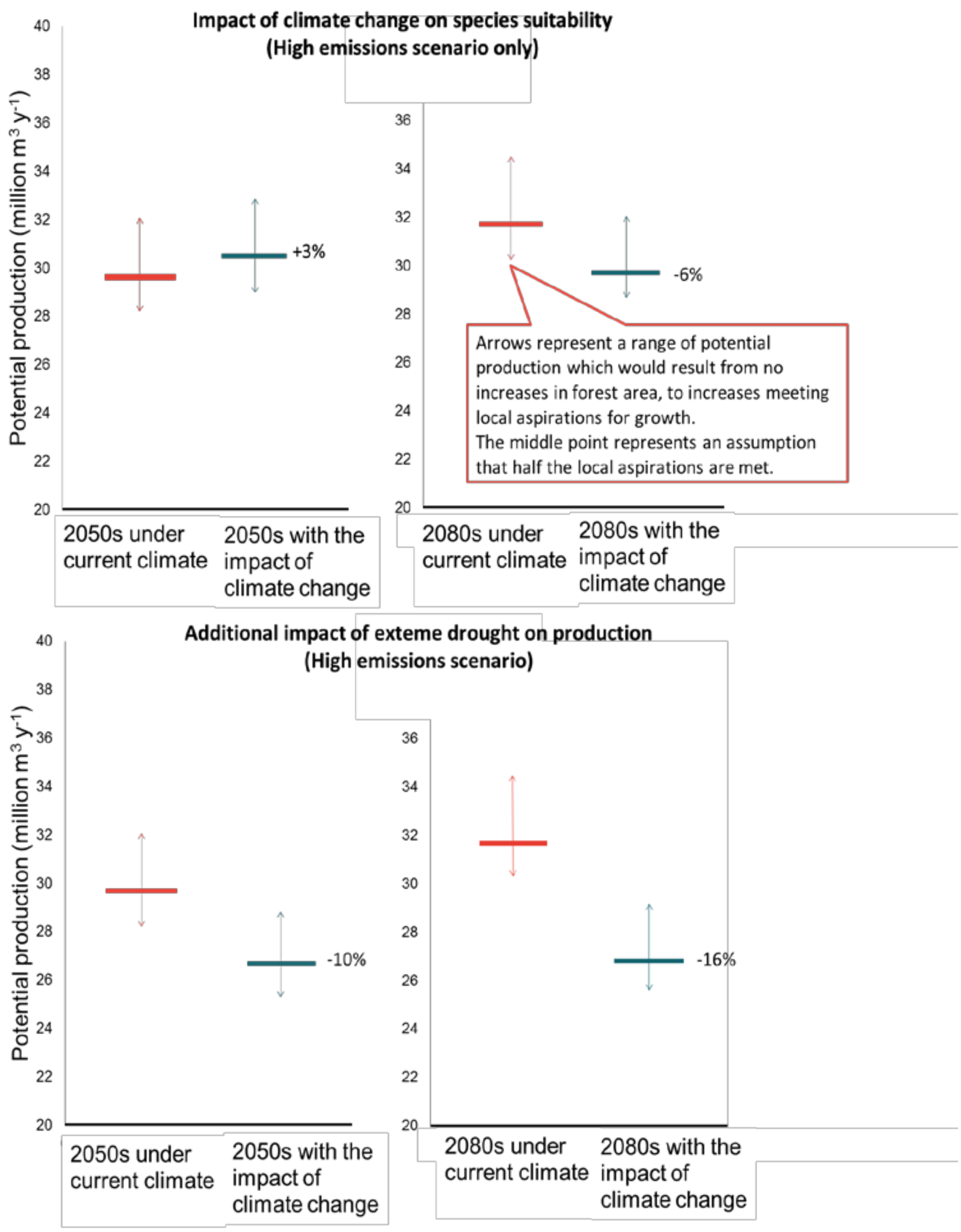


Source: ECR analysis based on ESC modelling of yield class to the 2050s combined with illustrated forest cover areas estimated for 2050 and 2080; and CCRA (Moffat *et al.*, 2012). Note that 2050 and 2080 are illustrated as they are intended to reflect annual impacts.

The percentages noted represent the change in potential production relative to the estimate in the absence of climate change. The projections of potential production are based on ESC estimates of yield class (which represent the maximum average rate of volume production per hectare of forest (in cubic meters of timber)). Depending on the age structure and diversity of management regimes of UK forests in the 2080s, the value of these ranges could be as much as two thirds lower.

Scale of the challenge

Although subject to uncertainty, the climate change impact on forest potential production across the UK is projected to be positive to the 2050s. However, by the 2080s the impact is projected to be negative.

In England, by the 2050s and 2080s, the impact is projected to be broadly negative. In Scotland, projections suggest opportunities from increases in yield class due to the climate being more suitable for the key species, assuming no significant drought events occur and that no serious pest or pathogen outbreaks impact the main tree species. However, because forestry in Scotland is highly reliant on only five tree species, exposure to new pests and pathogens could be high and yields would be expected to be heavily impacted if they emerge or become more prevalent between now and the 2080s.

Disaggregated projections

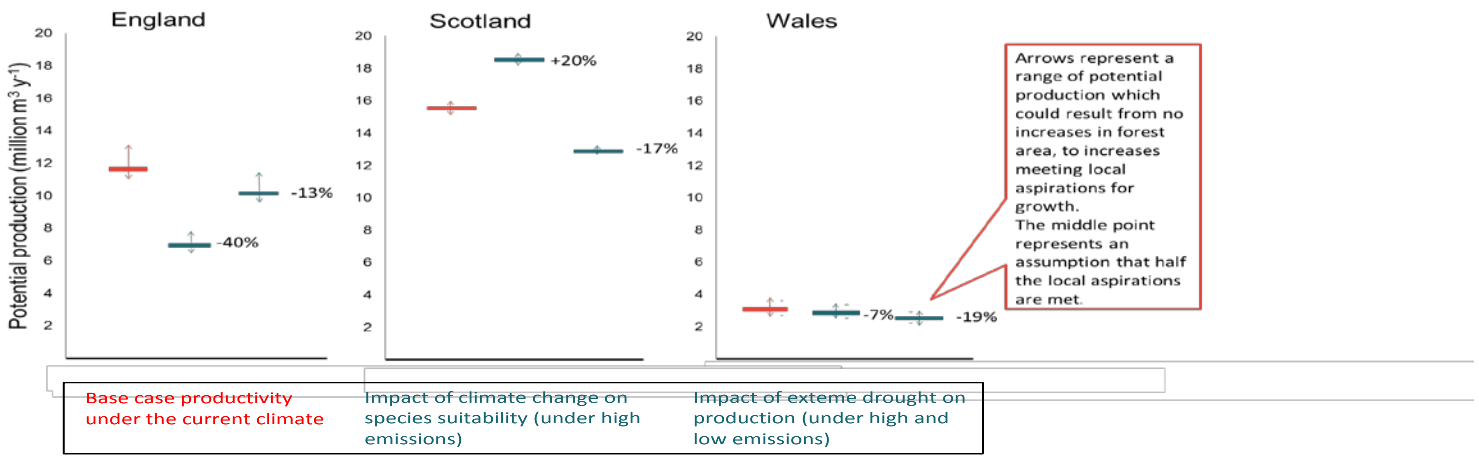
Figure 6 illustrates the projected impacts of climate change on potential production across England and the DAs. Localised impacts are often hidden when aggregated at a UK level. To interpret the chart:

- Various climate change impacts are plotted individually moving from left to right in the chart.
- The vertical arrows illustrate potential production under (i) high increases in forest cover and low emissions, and (ii) low increases in forest cover and high emissions.
- The percentages noted represent the change in potential production relative to the projected level in the absence of climate change.

Figure 6 suggests that climate change impacts on species suitability to their current locations could lead to potential production increases of around 20% in Scotland without further adaptation action.

Figure 6 also shows that although the impact of drought could be lower in England (if it occurs), the impact of climate change on species suitability in England is likely to be largely negative across most species and result in a loss of potential production of perhaps 40% before the risks of drought are considered.

Figure 6. Impact of climate change on projected forest production across England and the Devolved Administrations by the 2080s



Source: ECR analysis

The projections of potential production are based on ESC estimates of yield class (which represents the maximum average rate of volume production per hectare of forest (in cubic meters of timber) during its rotation) for the 2050s and 2080s, combined with estimated forest cover in the years 2050 and 2080. The years 2050 and 2080 are shown to demonstrate they are annual impacts. Depending on the age structure and diversity of management regimes of UK forests in the 2080s the value of these ranges could be as much as two thirds lower. Note drought refers to the same as the CCRA (Moffat *et al.,* 2012), which "excludes the positive effects of mild drought".

England

Of all UK countries, climate change is projected to have the greatest negative impact in England. It is estimated to experience a loss of production due to climate change even in years in which there is no significant drought event. This reduction is as a result of the climate conditions in the UK, particularly the South East, which are projected to be closer to the limiting soil moisture for many currently planted species.

The suitability of species in England is expected to suffer as a result of climate change. However, opportunities for species which currently grow well in southern Europe may be available. Sweet chestnut is currently the only species examined which is projected to show increasing yields.

Many tree species that are dominant in the south of the UK today may become dominant in the north of the UK in the future. This may result in a shift of species and habitats to the North and West. Estimated yield class change for beech ranges from -27% in the east to +9% in the north east of England for the 2050s (Moffat *et al.,* 2012)[28].

Compared to other countries, England has a lower proportion of softwood forest, a higher proportion of ancient woodland, and higher levels of ownership by charities and local authorities. The objectives of forest owners in England may therefore have a greater focus on a broader range of ecosystem services (such as biodiversity conservation or the use of forests for urban or peri-urban green space). Willis *et al.,* (2003) valued non-market ecosystems by country and assessed the value in England as £884 million, which was over eight times greater than that assessed for Scotland.

Scotland

Climate change impacts in Scotland are estimated to result in a wide mix of opportunities as well as adverse effects.

Projected climate change, including changes in temperature and soil moisture, are less likely to reach the extreme temperatures and moisture deficit regimes that reduce yields of current species. Instead, the warmer conditions and longer growing seasons are expected to increase productivity, at least in the medium term. Projections suggest there will be increases for most of the 14 examined species in this region.

Scotland currently experiences high winds and flooding. Resilient species and management techniques are already widely used to mitigate these risks.

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[28] This analysis has used simplifying assumptions in the model, where no biotic impact, effect of rising CO_2 levels or extreme events have been assumed.

Scotland is dominated by few species, predominately five key conifer species, with Sitka spruce alone making up 38% of all forest. This lack of species diversity arguably increases the exposure to risks from pest and disease outbreaks compared to other countries.

Wales

Figure 6 shows a projected fall of potential production of 7% in Wales by the 2080s, assuming no drought and no significant pest or disease outbreaks.

Temperature and moisture impacts on species suitability in Wales are predicted to decrease yields in all but Sitka spruce.

28% of the total forest area is Sitka spruce and, as with Scotland, this presents opportunities in North Wales for increased yields, but more exposure to pests and disease outbreaks, which may impact this species.

Northern Ireland

Limitations on data on the species distribution and climate change impacts in Northern Ireland mean the localised impact of climate change cannot be adequately assessed in this report.[29] Annex 3 details how Northern Ireland has been treated to assess the potential impact on the UK as a whole.

3.7.5 Impact of climate change on ecosystem services provided by forests

The impact of climate change on production and on forest growing stock is expected to affect a number of ecosystem services. This is explored in **Table 3**

[29] The version of the ESC (version 1.7) model used for this report does not extend to Northern Ireland. The distribution of species in Northern Ireland has not been published within the Forestry Statistics (2011) beyond a categorisation between conifers and broadleaves. Therefore the impact in this DA is relatively uncertain and an assessment of the impact of climate change in Northern Ireland alone has not been undertaken. In order to assess an indicative impact of climate change on the UK as a whole, in this analysis the weighted average yields across England, Wales and Scotland, and impact of climate change on those yields, are applied to the area of forest in Northern Ireland.

Table 3. Projected impacts of climate change on ecosystem services to the 2080s (current prices)* (relative to no climate change)**.**

	Impact of long term climate change (high emissions scenario)	Impact of drought (low and high emissions scenario)
Potential production (million m^3)	~ minus 2	~ minus 5
Timber value (£ millions)	minus 50 to minus 100	~ minus 4 to minus 138
Carbon dioxide value (£ millions)**	-£600 to -£2,900	-£30 to -£4,000

*Figures assume 50% of future forest land-cover aspirations are achieved and are undiscounted.

**As noted above, the stated valuation of carbon is probably an over-estimate, as it is likely that forest growth has been over-estimated. Furthermore, since much of the growth will eventually be harvested, much of the sequestered carbon will be re-emitted. However, when the timber replaces fossil-fuels directly (i.e. as wood-fuel) or indirectly (replacing 'carbon/energy intensive materials', there will be a contribution to overall emissions reduction. Range shown reflects low to high price per tonne of CO_2 (DECC, 2010)

The range of impacts presented here is based on yield class (which represent the maximum average rate of volume production per hectare of forest (in cubic meters of timber)). Depending on the age structure and diversity of management regimes of UK forests in the 2080s, the value of these ranges could be as much as two thirds lower.

This table reflects a static view only in a single year – carbon and potential production would change over time

Timber values are presented for a range of timber prices; those used by the CCRA (Moffat *et al.,* 2012) (low) and estimates from private forest managers (illustratively double the CCRA value). It should be noted that these values will only be realised when the stand is harvested and sold, if sold at all.

The potential production and carbon values reflect the growth in the 2080s. In practice, this may be lower in the future, depending on the use of timber.

With the exception of carbon emissions, it has not been possible to place a value on ecosystem services (such as recreation and biodiversity).

These ecosystem services are now explored in more detail.

The provision of timber for the wood trade (provisioning services)

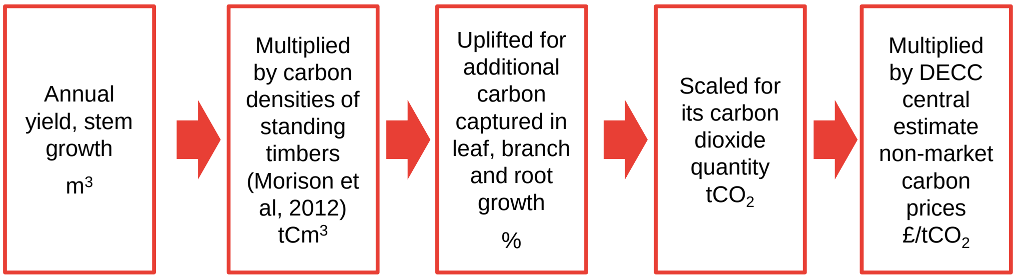
Estimates of the market price of softwood were applied to the potential production levels. Private forest managers suggest the market prices achievable for timber could be double those presented in the CCRA (Moffat *et al.,* 2012).

This analysis uses current timber prices achieved in the market although stakeholders expect prices to rise. As there are no published projections of timber prices, they are here illustratively assumed to remain flat (in real terms) in the future, although a sensitivity analysis assuming double these values has been undertaken. The market prices for timber will be subject to climate change impacts in Europe and other timber supplying countries, which compete with the local supply, and will also depend on climate change impacts on demand, such as the use of timber as a source of renewable energy.

The sequestration of carbon (regulating services)

Formal carbon markets (for example, the EU Emissions Trading System) do not currently apply to the forestry sector. However, carbon-based revenues from woodland creation can be realised through *ad hoc* agreements for woodland certified to the Woodland Carbon Code.

In the approach used here, the estimated carbon value of the potential production has been calculated by:



The carbon values presented may overestimate the amount of carbon stored, as removals through thinning and harvesting are not accounted for (although this could be largely be balanced by carbon storage in harvested wood products, which is also not accounted for). There may also be benefits not accounted for in the form of timber substituting directly for fossil fuels in the case of wood-fuel used for energy production, or indirectly through wood replacing more energy-intensive materials, such as concrete and steel in construction. Valuations are based on DECC non-traded prices per tonne of CO_2.(low to high and central)

Biodiversity (cultural and supporting services)

The England Biodiversity Strategy (Mitchell *et al.,* 2007) reviewed potential impacts of climate change on woodland and forestry habitats and biodiversity, including the following:

- "climate change will not cause woodlands to become completely different habitats, even where sensitive tree species die, other species would be expected to replace them"[30].
- Changes in growth cycles and community structure regarding dominant species may be expected[31].
- Changes in the current distribution of species geographically "will be limited", with some broadleaf woodland in the South East facing decline[32].
- The services provided by forests of preventing soil erosion could decrease.
- There may be a reduced focus on maintaining biodiversity in areas where productivity increases and timber production becomes more profitable.[33]
- Climate change may increase the value of ecosystem services to humans, for example, in relation to services such as the interception and capture of rainfall in forests, control of soil erosion and provision of shelterbelts and cool shaded areas.

Discussions with experts suggested that climate change is more likely to cause changes to habitats and biodiversity than a loss or degradation of ecosystem function. These changes are varied and complex, and expected to be both positive and negative. The net impact of changes is therefore largely unquantifiable at present. For this reason, this analysis does not attempt to quantify changing forest biodiversity.

[30]Rising temperature and changing rainfall patterns are starting to have an impact on biodiversity in the UK (Mitchell *et al.,* 2007). The impact of climate change on species suitability is likely to be dependent on the distribution of habitats; in areas where species suitability declines habitats supported by these species will change, however, other species would be expected to replace them. The presence of particular tree species can be important where other species are dependent on them, such as epiphytes and canopy invertebrates. Overall, climate change is more likely to cause an adjustment of species composition and dominance rather than loss of woodland (Mitchell *et al.,* 2007).

31 Most woodland species are not at the southern limits of their range and are unlikely to suffer significant mortality either as a direct result of exposure to increased temperatures or through competitive exclusion by other species which may thrive better under changing conditions. However, changes in leafing dates of trees are expected to have consequences for ground flora, and loss of synchrony between flowers and pollinators and predators and prey.

[32] There could be some loss of habitat due to summer drought, which is most likely to affect broadleaf woodland due to its widespread distribution in the South East of England. Mitchell *et al.,* 2007 note that the following habitats are those of greatest concern: lowland beech and yew woodland, lowland wood-pasture and parkland, upland mixed ashwood, upland oakwood, and wet woodland.

[33] Where productivity increases, more frequent harvesting, or harvesting at different times of year, may have an additional impact on the habitats which exist within those forests (Mitchell *et al.,* 2007).

A decline in biodiversity is likely to be valued more negatively where it occurs in ancient woodland.

Recreation (cultural services)

Owing to a lack of available evidence, it has not been possible to assess in detail the impact of climate change on the recreational and landscape value of UK forests. The following case study illustrates the way in which recreation services provided by forests can be affected when a forest is affected by a pathogen.

Case study: impact of the loss of forest on recreation

Afan Forest Park is a 12 km^2 forest park set in the Afan Valley, Wales. It has a network of world-class mountain bike trails, family cycle routes and marked walking trails, attracting over 100,000 visitors every year. There are also a number of supporting accommodation enterprises catering, primarily, for the needs of cyclists using the mountain biking facilities.

The Afan Forest had a large proportion of larch species. In 2010, 18% of the forest was affected by felling required to reduce the spread of the pathogen, *Phytophthora ramorum*. This had an extensive visual impact on the adjacent visitor centre and within the Afan valley as a whole. Sanitary felling has since also been required in large areas of Wales and the South West of England.

Since the sanitary felling for *Phytophthora* within the valley, the mountain bike trails have been affected with section closures and diversions and user numbers have decreased. Local tourism-related businesses have noted a marked impact on trade as a consequence. This factor, coupled with poor seasonal weather, compounded the impacts of the felling.

Before the felling there were 13 well-used walking trails within the forest park (10 Forestry Commission trails and 3 Community trails). Since the *Phytophthora*-related felling, that number has reduced to 5 Forestry Commission trails, with the 3 Community trails continually affected by closures and diversions. This again has had an impact on the visitor numbers and a knock on impact on local businesses.

Source: Price (2012)

Uncertainties

The key uncertainties in this assessment include:

- Potential production is based on yield class, which assumes an even distribution in the age of trees. In reality, this will vary over time, depending on the cycle of new planting and restocking.

Scale of the challenge

- The assessment estimates yields in forest owned or managed by the Forestry Commission. Owing to the absence of information on the location of individual species across private sector woodlands, it has been assumed that species in private sector forests would be impacted by climate change in the same way as for public forests, and that soil types represented in the public forest reflect those across the private sector. Making this assumption allows private sector forests to be incorporated into the analysis, extending the analysis published in the CCRA (Moffat *et al.,* 2012).

- Climate change impacts the productivity of different tree species to greater or lesser extents depending on location. The distribution of such species to locations within individual countries of the UK is based on that of the Forestry Commission's forest and applied to private land.

- The distribution of total broadleaf area between species is based on an inventory concluded between 1995 and 1999 (National Forest Inventory 2011 with 2012 updates). Where this inventory differs to the distribution in 2011, the overall impact on production of all species will differ. Projections of forest-cover to 2050[34] and 2080 presented have made a simplifying assumption that species proportions (and their respective locations) in 2011 will remain constant as new forest is planted.

- Projections do not cover the full range of possible climate impacts and the range of uncertainty posed by projected climate change is very wide. Low probability, high impact events could have far greater impacts than shown in this analysis, for example.

The analysis in this report relies on a number of assumptions. **Table 4** describes the implications for the projections of making these assumptions.

This Section has explored the potential scale of challenge facing the forestry sector as a result of climate change. The next Section considers the context for adaptation in terms of the adaptive capacity of relevant actors.

[34] Note that yield class projections for the 2050s and 2080s are used from the Forestry Commission's ESC model; for the purposes of this analysis, forest cover has been estimated for the particular years of 2050 and 2080, based on published aspirations for increasing forest cover in the countries of the UK.

Table 4. Assumptions made and their implications

Sensitivity	Assumption	Implication
Increase in forest cover	Increases in forest cover may continue at current levels. However, Governments of Scotland, Wales and Northern Ireland have announced ambitious aspirations for forest land-cover to the middle of the century.	Planting new forests offers an opportunity to account for adaptation in species choice and forest management.
The impact of rising CO_2 on yields	The ESC model does not account for the positive impact of rising CO_2 levels when projecting yield class.	Yields could be higher than projected in this analysis.
Emissions scenario	Impacts of drought have been modelled under high, low and medium emissions scenarios. The impact of climate suitability for different species has only been modelled under a high emissions scenario.	Projections of species suitability could be pessimistic. They use a single scenario for simplicity to illustrate the potential scale of risk – projections are not intended to reflect a likely future.
Occurrence of significant or prolonged drought	The impact of drought has been included in this assessment.	There may be years where drought does not occur. If it should occur, the impact of drought would in practice vary by its severity, duration and frequency of recurrence.
Competing uses for water from drought	The projected impact of drought on forests does not consider competing uses of water in the future, for example from increased human population pressures.	Water shortages may alter approaches to catchment management, in turn affecting decisions over forest versus other land-cover.
New pests and pathogens and the species they impact	The pests and pathogens modelled are current examples; the extent to which these would be present in the future, and the viability and emergence of new pests and pathogens is not possible to predict.	Impacts of pests and pathogens are indicated by current knowledge. Monitoring over time would be required for more detailed analysis.
Market price of timber	Market prices used in the analysis are the same as in the CCRA (Moffat *et al.,* 2012) (based on Forestry	A range of values have been presented to capture the range of price

Scale of the challenge

	Commission timber sales). Discussions with stakeholders suggest timber prices could be around twice the values assumed. In addition prices paid for firewood and wood fuel will be higher. No published estimates exist of projected timber prices.	estimates.
Carbon sequestered into soils by trees	Woodland planting generally results in an increase in soil carbon levels compared to the previous land-use. However, climate change may increase the loss of carbon from soils.[35]	The amount (and hence monetary value) of carbon sequestered could be higher than assumed.
Carbon released in harvested timber	When timber is harvested the majority of the carbon sequestered during growth will return to the atmosphere. This may be either immediately, if the wood is used for fuel, or over longer periods, in the case of durable wood products. If the principles of sustainable forest management are applied, CO_2 released by harvesting trees will be sequestered by growing trees, preventing a decrease in current stocks of CO_2 in UK forests. As a result, the use of timber as fuel (or durable wood products replacing materials with high energy inputs required for their production) may substitute for fossil fuels resulting in lower net carbon emissions. This report assumes no loss of the sequestered carbon back into the atmosphere.	Net carbon emissions mitigation in the long-term could differ from that assumed.

35 In many areas, increased temperature and CO_2 concentrations will increase the rate of sequestration by vegetation (except where drought limits growth), but this is likely to be balanced by increased rates of soil respiration in the short to medium term. In the long term, it has been claimed that the increased rates of soil carbon loss will outweigh the sequestration by vegetation, and the terrestrial biosphere will become a net carbon emitter (Cox *et al.,* 2000). This applies to old growth forest, not to forest in its active growth phase that typifies the majority of woodland in the UK. This may be true for natural vegetation, but for production forestry, the increases due to rising temperatures and CO_2 levels are likely to be ongoing and outweigh losses of soil carbon.

4 Context for adaptation

Key messages

- Adaptive capacity is the ability of a sector, and the actors within it, to take action to adapt to climate change. Adaptation action includes measures which organisations and individuals are expected to take to respond to the impacts of climate change.
- **Adaptive capacity of the sector overall is considered to be relatively high within the larger organisations, such as the Forestry Commission, commercial forestry companies and large estates**. There are also a number of systems in widespread use in the sector (most notably the UK Forestry Standard's Forests and Climate Change guidelines), which are important mechanisms for supporting implementation of adaptation measures. These are supported by Government policy, including commitments to sustainable forest management and promoting the multiple benefits that forestry can provide. For the smaller woodland owners, however, adaptive capacity is substantially lower.
- Over the next 10-20 years, however, adaptive capacity is limited by the narrow range of species that are considered for 'commercial forestry' in the UK, the lack of significant stocks of alternative species and provenances in forest nurseries, and reticence of timber processors to consider alternative species where current timber volumes of those species are low.

4.1 Introduction

This section focuses on the context for adaptation, including describing the policy framework affecting woodlands in the UK and assessing of the adaptive capacity of relevant (non-government) actors.

Whether adaptation action is likely to be taken to address climate threats effectively requires two key factors to be considered:

- **Adaptive capacity (see below):** Adaptive capacity is a necessary condition for the design and implementation of effective adaptation strategies, so as to reduce the likelihood and magnitude of harmful outcomes resulting from climate change (Brooks and Adger, 2005).
- **Adaptation actions (see Section 5):** There are many adaptation actions that individuals and organisations are already taking in some parts of the

sector, and which would be expected in the future. These may be in response to an event or consequence of climate change (reactive) or as a result of government policy (planned). Adaptation actions can focus on building adaptive capacity, on reducing the climate impact or maximising the opportunity. There is a suite of actions that could form part of an effective adaptation strategy. The choice of actions will depend on the capacity of both the organisation and the sector in which it operates, and the climate change risks under consideration – these factors should be considered systematically together with non-climate risks.

The role of policy is first considered, before assessing adaptive capacity.

4.2 Impacts of government policy

Following Government commitments to sustainable forest management and reflecting the multiple benefits that forestry can provide, forestry policy balances the needs of biodiversity, timber production and other ecosystem services. Although there are currently grants for woodland creation, these may be insufficient for extensive woodland creation owing to the relatively higher return (where viable) from agricultural use of the land.

Schemes such as the Woodland Carbon Code and other initiatives being developed are, however, expected to have a major impact on woodland income, by encouraging investment from firms, consequently impacting on woodland creation.

The UK Forestry Standard is the standard for sustainable woodland management and a requirement for receiving grant-aid. The UK Forestry Standard, UK Woodland Assurance Standard, Glastir Woodland Management (Wales), Sustainable Management of Forests (Scotland) and other initiatives and guidance promote management practices that enhance structural and species diversity. These make an important contribution to a healthier and more resilient woodland network.

The market's failure to recognise the wider benefits of woodland justifies Government action, but there are still further opportunities to encourage the planting and sustainable management of woodland in the UK.

Current policy relevant for forests is described in further detail in Annex 4.

4.3 Adaptive capacity

For the purposes of the ECR, adaptive capacity, or the ability to adapt, is analysed using a simplified framework informed by the Performance Acceleration through Capacity Building (PACT)[36] model (Ballard *et al.,* 2011) and the "weakest link" hypothesis[37] (Yohe and Tol, 2002; Tol and Yohe, 2006). Both PACT and the weakest link models introduce the idea of discrete levels of an attribute and allow identification of where an actor is now and where they would like to be. They illustrate the areas that need most development to get to the desired end point (Lonsdale *et al.,* 2010).

This definition of adaptive capacity is consistent with that of the CCRA (Moffat *et al.,* 2012), as shown in the box below.

Adaptive capacity

"The ability of a system/organisation to design or implement effective adaptation strategies to:

- adjust to information about potential climate change (including climate variability and extremes);
- moderate potential damages; and,
- take advantage of opportunities, or cope with the consequences"

Source: Ballard *et al.,* 2011 (CCRA – modified IPCC definition to support project focus on management of future risks)

In assessing the ability of the forestry sector to adapt to projected impacts of climate change, this project considers two factors: the structure of the sector in general terms (i.e. the role and size of different organisations involved), and the organisations within the sector - the function of key players who make critical decisions and their performance (i.e. gross margins, outputs and benefits delivered). An analysis of these two factors describes the ability of the sector to adapt to climate change and the extent to which opportunities and threats described in Section 3 are likely to be addressed. It should be noted that adaptive capacity is not only needed to optimise decisions based on climate change

[36] This model was chosen as it was used in the CCRA, from which this project follows on, and because in a UKCIP review of adaptation tools it was ranked as the most robust (Lonsdale *et al.,* 2010). The PACT model identifies six clear stages of development when organisations take on the challenge of climate change. These are called response levels (RLs) rather than stages as each level is consolidated before moving to the next. RLs 2 and 3 are characteristic of 'within regime' change, RL4 is characteristic of 'niche experimentation' (or 'breakthrough projects') and RL5 is conceptualised as regime transformation. RL6 would be conceptualised at the landscape level. In this report, the RLs were used very simplistically as a comprehensive assessment of the adaptive capacity of the sector using PACT could not be undertaken as further detailed engagement with actors would be necessary. It is recommended that this be undertaken in further work.

[37] The weakest link hypothesis enables assessment of the potential contribution of various adaptation options to improving systems coping capacities by focusing on the underlying determinants of adaptive capacity. In this report, the determinants were used to assess capacity of an actor rather than an adaptation option. This was used as it provides socio-economic indicators by which an actor's adaptive capacity may be categorised. It enables the weakest part of an actor's capacity to be shown, providing an area to focus adaptation responses.

adaptation, but for other decisions with long-term implications (Ballard *et al.*, 2011).

Structural adaptive capacity

The analysis of structural adaptive capacity is based on evidence from published studies and qualitative evidence from interviews with a wide range of experts within the sector (Annex 1). The interviews were conducted under Chatham House Rules; stakeholders are not referred to individually or by name.

Adaptive capacity of the sector overall is considered relatively high within the larger organisations, such as the Forestry Commission, commercial forestry companies and large estates. In the **short term, i.e. over the next 10-20 years, the capacity is lower**, as the sector cannot change the current distribution and species mix rapidly.

However, adaptive capacity is lower for owners of smaller woodlands. Consistent underlying factors, emerging from stakeholder interveviews, include the perceived or actual cost and time involved for various forest management activities (e.g. the approvals process for felling >5 m^3), as well as a lack of understanding of the benefits involved.

This description of structural adaptive capacity can be used to **identify specific types of decisions where further assessment of climate change implications will be important**. These include:

- Planting new forests to increase resilience to climate change;
- Forest management where decisions today can have long term implications; and,
- Co-ordination of forest management at a landscape scale, including incorporating the value of ecosystem services into decision-making.

These decisions are assessed in detail in Section 4.3.

Sector complexity

The forestry sector contains a number of large organisations that range in scale of holdings, including larger organisations such as the Forestry Services (including Forestry Commission in England, Scotland, and Wales; the Northern Ireland Forest Service) plus Forest Research (an Executive Agency of the Forestry Commission), major timber growers, and major timber processors, and a large number of small woodland owners. While the ability to influence the former is well-established, it is harder to engage with the latter.

An underlying driver of complexity is the variation in types of forests in the UK. This includes tree type (e.g. coniferous or deciduous), species, age (ranging from recent plantations to ancient woodland), and growing conditions (e.g. soil type and quality, or wind exposure). These vary across specific locations and across England and the DAs.

In addition, there are various management objectives for forests. These include: timber production, protection of biodiversity and recreation, among others. They are influenced by various stakeholder expectations, including access and landscape design (Starr, 2005).

Interdependencies

The sector has many **interdependencies** with other sectors (particularly land-use and planning, natural environment and energy), which potentially leads to trade-offs between them (e.g. food production and environmental protection: Read *et al.,* 2009a). Such interdependencies can weaken adaptive capacity because of the lack of a single desired direction and clarity of responsibility. Conversely, farmers using trees to provide an important service to enhance production can build capacity.

Decision lifetime

A key issue within the forestry sector is the long-life of its assets (i.e. trees). As discussed earlier, only 0.2% of forests in England are currently felled and re-planted each year (though it is noted there are aspirations for an expansion of forest area). Following establishment, the forest then requires ongoing management, through weed and pest control, pre-commercial thinning, and harvesting.

For many forests, activities at the regeneration phase have the greatest long-term impact (Kolstrom *et al.,* 2011). Therefore the sector cannot adapt or change quickly and "there is a limit on the ability to change species and practices in response to a change in climate" (Read *et al.,* 2009a).

Activity levels

The frequency of intervention depends on the management regime used. For lower impact silvicultural systems (including continuous cover forestry), there is a greater frequency of intervention, and more monitoring of the stand as it transforms is required to ensure that intervention is both well-timed and produces the intended change (Ray *et al.,* 2008).

Maladaptation

Maladaptation is considered to be "action or investment that enhances vulnerability to climate change impacts rather than reducing them." (UKCIP, 2012)

There are examples of maladaptation across all types of forest owner. For example, the nature conservation community is not always clear on its conservation goals in a changing environment and whether the past emphasis on use of native species and local provenances is still valid (Read *et al.,* 2009a).

The long-term nature of forestry also means that management objectives set under current climatic conditions may not apply in the future. Indeed, one stakeholder pointed out that some of the mature oak trees in existence today were planted to provide timber for the manufacture of wooden ships.

For many farmers with small patches of woodland, creating productive forests or structures to cope with all conditions is not a priority (Yeomans and Hemery, 2010). As a result, the potential for ineffective adaptation or maladaptation through lack of consideration of synergies or trade-offs between different ecosystem services is high.

Organisational adaptive capacity

Table 5 below presents a summary of the adaptive capacity of actors in the forestry sector. **Unless otherwise specified, the data have been compiled from interviews with stakeholders, experts and findings from two focus group discussions.**

Table 5. Organisational and adaptive capacity

Actor	Resources	Processes	Organisation	Summary
Forestry Services (e.g. Forest Research, Forestry Commission).	Awareness of relevant climate issues to the 2050s and beyond is high. Able to invest in research and develop best practice. Experienced and trained foresters;	Established processes for forest design planning and operations. Measures in place to roll-out good practices to other owners. Conducted climate change risk assessments. Initiatives are in place to integrate climate change adaptation into management practice. Public forests are managed to the requirements of UKFS and UKWAS (both of which include climate change adaptation elements). FC can also require other owners to follow these requirements. Monitoring and evaluation data are collected but much of this data are unprocessed and lacks analytical value.	Management sees climate change as a key issue. Strong collaboration between different forest districts and between DAs. Through felling licenses, grants etc., able to engage with forest managers under all other categories.	High – considers implications for overall regime reform and transformation.
Commercial operators	Experienced and trained foresters. This has been stronger in production compared to ecosystems services. Financial resources available but operating to tight margins.	Business planning often operating on a 30-40 year time-frame. Apply best practice for forest planning and operations rapidly, as described in UKFS/ UKWAS. Operators will experiment using new species/ southerly provenances to an extent.	Strong internal management and engagement with others in sector through associations etc.	Medium – High Examples of effective management and also considering experimentation to adapt to uncertainty.
Large mixed estates	Multiple sources of income including property, sporting activities, agriculture. Operating at a scale sufficient to employ professional foresters/advisors. Area under management normally >40 ha.	Decision-making conducted at an estate level often considering implications beyond 50 years. Conservatism could restrict ability to adapt. Applies forestry best practice over a reasonable period of time. Usually uses established species and provenances and is tied to woodland grant schemes; UKFS requirements on adaptation are generally met.	Some engagement with others through associations, and through advisors.	Medium adaptive capacity affected by sources of income, size and owner characteristics (often high levels of interest in climate change but conservative approach to management). Operates at a scale able to ensure effective management.

Actor	Resources	Processes	Organisation	Summary
Farmers	Family-run farms with limited access to finance for forestry. Lack of knowledge (e.g. only 4% farmers seeking advice about climate change impacts: FPS, 2011).	Prominence of short-term decision-making driven by productivity and market forces. Uncertainty of legislation (e.g. CAP) makes it difficult for farmers to adapt. In some cases, limited operations (e.g. coppicing, thinning, felling, replanting). Management normally not tied into forestry grants so UKFS requirements may not be followed.	Limited collaboration with others. Historically some resistance to change; however this is changing as younger generations come in with new approaches.	Substantial variation in adaptive capacity; however, as forest management is often not a core part of the business, capacity is often low.
Small scale landholders/ hobby owners	Resources based on individual income with typically limited knowledge of forest management (and climate change).	Decision-making based on personal priorities and often not formalized. In some cases, limited operations (e.g. coppicing, thinning, felling, replanting) or management processes. Existing management normally not tied into forestry grants.	Limited collaboration with others. However, in some cases owners are members of groups representing small woodland owners.	Generally, fairly low adaptive capacity.
Organisations managing for other purposes (e.g. conservation)	Generally high levels of awareness of climate issues, especially in larger organisations. Resources depend on diverse sources of income.	Established processes for management planning. These often focus on other (shorter-term) pressures such as deer, squirrels etc. Limited processes to introduce species from outside the British Isles.	Collaboration with similar organisations and surrounding land-owners.	Medium adaptive capacity but varies by type of organization.

In addition to the organisations listed above, organisations in related sectors can play an important role. For example, a wide range of organisations are involved in addressing wildfires: Fire and Rescue Services, via the Department for Communities and Local Government, are responsible for extinguishing fires (Fire and Rescue Services Act, 2004) and are responsible for assessing the main causes of fire. However, management of the fuel and vegetation rests with another government department (Defra) or the landowner.

Adaptive capacity of the sector overall is considered to be varied. There are a number of key implications for the extent of adaptation actions arising from this analysis:

- The Forestry Commission plays an important role in setting standards; the UKFS includes Forests and Climate Change Guidelines which have to be met in order to receive grant aid (Forestry Commission, 2011a). Land-owners also respond to other stakeholders, such as certification and accreditation bodies (UKWAS). Furthermore, the sector is subject to considerable stakeholder attention and engagement: the Independent Panel on Forestry is reported to have received over 40,000 responses for their review illustrating the degree of attention on woodland management. (Woodland Trust, 2012).

  A key element of adapting to climate change is the extent to which different land-owners and other stakeholders are prepared to accept change. This includes accepting lower productivity (i.e. yield class), or changes to the structure and composition of native woodland plant communities.

- In managed woodlands, the sector is effective at identifying or creating best practice to ensure resilience under today's business models. There is a substantial gap in the under/un-managed woodlands, with only 57% of forest land across the UK with an approved management plan or equivalent (Gillam, 2011). This problem is particularly acute in England where only 48% of the woodland area is covered by a management plan.

  An important factor is the **rate of return** experienced by woodland owners (one stakeholder indicated a possible real rate of return could be around 3% (conifers) and 1 % (broadleaves). This is compounded by the level of support available for smaller woodland owners: in England, 45 woodland officers have the task of providing advice and guidance to approximately 60,000 owners (FCE, 2012).

- There are some areas of strategic experimentation, such as developing incentives through payment for ecosystem services, including the development of the Woodland Carbon Code, to promote woodland expansion projects. Examples include projects undertaken to reduce the impacts of flooding from forestry (Odoni and Lane, 2010). The Environment Bank, through which organizations can "purchase credits to fund the creation and/or management of an ecological or environmental resource" (Environment Bank, Accessed May 2012) also provides funding that could be used to promote adaptation. Likewise, the National Forest is a geographically focused woodland expansion programme operated on a sufficient scale to allow different ecosystem services to be accommodated. Further potential exists in areas such as long-term trials and tree breeding.

5 Adaptation actions

Key Messages

Adaptation actions can include measures to build adaptive capacity and / or reduce specific risks associated with climate change.

Efforts to increase the extent of forest cover are in place; in many cases these will not only increase resilience to climate change in existing forests but also build on ecosystem services provided by forests. The potential to increase the level of effort in this area is substantial.

Evolutionary adaptation is promoted in actively managed woodland through regular regeneration, while management also provides opportunities for more interventional adaptation measures to be implemented. However, a substantial area of UK forest is not managed and has no management plan. This is compounded by the limited capacity of forestry extension services.

Evidence suggests that continuous cover silvicultural systems will generally develop stand structures that are more resilient to climate change. However, such systems are not widely practiced across the UK.

There are a number of risks, most notably from pest and disease outbreaks, for which adaptation measures are available and are being applied. However, given the uncertainty over future pest and disease outbreaks, even if adaptation measures are implemented, the residual impact could be high

This section provides an overview of some of the categories of actions different actors in the sector are already taking, and would be expected to take in order to maximise opportunities or minimise climate risks. Barriers to effective adaptation are identified.

5.2 Categories of adaptation actions

The categories include actions to build adaptive capacity as well actions that reduce the particular risks of climate change. These categories of actions were informed by key sources of literature and discussions with sector experts. They were then refined and verified in the stakeholder interviews to ensure that the ECR considered the key sorts of actions to address the particular risks considered.

Much of the literature on adaptation to climate change has been at a conceptual or generic level (Adger *et al.,* 2007; Howden *et al.,* 2007; Iglesias *et al.,* 2007). This has shaped the understanding of what adaptation is, and the importance of the processes and responsibilities regarding adaptation. However, less research exists to quantify the predicted effects of actions in managing climate impacts on forestry and associated ecosystem services.

For the purposes of the ECR, the adaptation actions considered are those that are already being taken, or are expected to be taken in the near-term (to 2020). The actions include adaptation that is:

- **Planned adaptation:** this tends to be (but is not exclusively) anticipatory adaptation, undertaken or directly influenced by governments or collectives as a public policy initiative. These actions tend to represent conscious responses to concerns about climate change (Parry *et al.,* 2007).

- **Reactive adaptation:** is taken as a reactive response to climatic stimuli as a matter of course (without direct intervention of a public agency) (Parry *et al.,* 2007).

In some cases, actions could be considered both planned and reactive (for example, a reactive response to a current risk could lead to planned adaptations to limit future exposure). Both planned and reactive adaptations might be 'wrong' or lead to maladaptation in the long-term or for wider society, and may need to be countered with further action, such as building adaptive capacity and by taking specific actions to change and deal with the consequences.

These categories of measures were informed by review of published and/or grey literature as well as contributions from an expert panel. They were then refined and verified in the stakeholder interviews to ensure that the ECR considered options to address the main risks.[38] The stakeholders interviewed are set out in Annex 1. The interviews were conducted under Chatham House Rules, and so stakeholders are not referred to individually or by name in this report.

The adaptation options discussed below are categorisations of a number of individual actions, which in future, could be disaggregated. Adaptation actions are organised according to scale of operation:

- **Forest-level measures** include actions to diversify species and woodland structure. It also includes activities at a wider scale and scope (e.g. including non-forestry areas into planning, altering the forest infrastructure - roads, drainage, and altering access - to respond to impacts such as fire, pests and pathogens, and flooding.

[38] The stakeholders interviewed are set out in Annex 1.

- **Stand-level[39] measures** include a) species and provenance selection and b) use of alternative silvicultural systems.

- **Landscape-level measures** include woodland creation as well as planning to address issues such as catchment management, habitat connectivity and habitat fragmentation.

There are a number of adaptation measures that operate at all levels, most notably species diversification and enhanced monitoring & evaluation. A review of these measures is included in each section. This report has considered measures individually; naturally each measure could have a co-benefit or a negative side effect.

A suite of actions could form part of an effective adaptation strategy. The choice of actions will depend on the adaptive capacity of the organisation, the sector in which it operates, interdependencies, and the climate change risks under consideration. These factors need to be considered systematically, together with all non-climate risks.

Each measure is considered using the same approach: the measure is described, before assessing the current and anticipated level of uptake. The assessment of uptake is based on analysis of the key barriers and enablers and the extent to which they are likely to be significant. Finally, an initial view of the potential effect of the measure is discussed. Each of these variables is categorised into high/medium/low by the ECR team before being validated by a selection of stakeholders and experts.

5.3 Forest-level measures – bringing woodlands under management

Management of woodlands is a necessary condition for adaptation: it promotes regeneration and natural evolutionary processes; it also allows diversification through planting of resilient species. By being under management, it is possible to have plans for monitoring and follow an adaptive management approach.

Woodland management includes a wide range of different measures such as:

- **Ride-cutting** to provide biodiversity benefits by creating open and woodland-edge habitat, as well as access for recreation.

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[39] A stand is a group of trees that are more or less homogeneous with regard to species composition, density, size, and sometimes habitat.

- **Coppicing** over a 15-20 year rotation period, to produce timber and wood-fuel, while at the same time providing high value habitat.

- **Thinning** to enhance timber quality by selection, improve growth of the remaining crop and promote biodiversity by increasing light penetration to the forest floor.

- **Controlling** weeds, invasive species, pests and diseases.

- **Managing infrastructure** such as forest roads, culverts and paths.

An important aspect of woodland management is the development of management plans. A management plan is "the foundation of sustainable woodland management…it identifies the existing value of the woodland (economic, environmental and social) and the owner's objectives. From this, the plan then sets out how the woodland will be managed in the short- and long-term." (Woodland Planning Grant, Forestry Commission website, accessed October 2012).

In addition to these generic interventions, there are a number of other specific forest management measures within this category:

- **Water management:** this includes building infrastructure, such as drainage to accommodate increased winter rainfall. It also includes measures to prevent flooding by maintaining vegetative cover within a watershed. Current guidelines, for example, restrict felling to 20% of a forest over any 3 year period in catchments where there are risks of flooding.

- **Fire management:** this includes preparedness (e.g. fire plans/maps, operating procedures, training, resilience planning, partnership working); prevention (e.g. linear fire breaks and belts, area vegetation fuel management active timber management, prescribed burning, fire patrols); response (e.g. improving initial attack, supporting long duration incidents), and recovery (e.g. salvaging crops and facilities, restoring habitats and species, and repairing remaining stands) (Forestry Commission, 2012b).

- **Pest and pathogen management**: this includes pest risk assessment, preventative measures (e.g. fencing, monitoring), and direct control by pesticides etc. Critical responses also include using silvicultural systems that avoid stands of high structural uniformity and encourage mixed species. (e.g. Kolstrom *et al.,* 2011).

A summary of adaptation measures related to forest management is included in **Figure 7**.

Adaptation actions

Figure 7. Summary of adaptation measures for forest-scale management

Measures to bring woodland into management including thinning, harvesting, replanting, weed control, can be managing to UKFS or UKWAS recommendations as well as water management, fire management. (preparedness, prevention, response & recovery) and pest and disease management (risk assessment, preventative measures & direct control)

Barriers

- Impacts from today's actions realised in 50-100 years time
- Awareness of changes to forest management guidelines
- Costs of certification.
- Costs of management
- Knowledge, skill among owners of unmanaged woodland,.

Enablers

- Actions required through the UK Forest Standard
- Support through grants , advice, communications, and regulation
- Examples of existing initiatives (e.g. water resource, wildfire)
- Market drivers for investment may encourage active management.
- Case for more active management is strong where weather events are already well understood.

Outcome

Extent of adoption: Medium (<30% of non-FC woodland in England receives management grants & aligns with UKFS; 45% of woodland use of forest certification schemes;).. This is likely remain constant on the larger and commercial forests . Response to pests/ diseases can be high with regulation/ incentives

Effects : Bringing forests into management acts as an enabler for many other actions.

	Current levels of adoption	Anticipated levels of adoption	Timing to observe effect	Cost	Effect (incl. co-benefits)
Water resource	Med	Med	10+ yrs	Med	Med: Initiatives avoid 5-10% of required flood storage investment
Wildfires	Med/High	High	5-10 years	Med	Med: Impact low-levels of risk but larger fires may not be controllable
Pests	Med	Med/High	5+ years	Med	Med/High: Hold progression of some insect pests; others not controlled
Diseases	Med	Med/High	Variable	High	Low: Once established diseases could still result in 10-50+% reduction in production

Source: Based on evidence from published sources and stakeholder interviews

Current/ future extent of adoption

The auditing of forest management measures is extensive across the public estate. In the private sector, assessment of application is linked to sampling of forests subject to felling grants/ licences and certification schemes. These have generally indicated high levels of uptake of standards, which is unsurprising given that adhering to UK Forestry Standard is a requirement of grant-aid through woodland grant schemes.

A general indication of levels of adoption of forest management is shown by the extent of woodland in the UK having to meet the requirements of UKFS (Forestry Commission, 2011a)[40]. This includes the areas of woodland receiving

[40] "The third edition of the UK Forestry Standard identifies eight elements of sustainable forest management: general forestry and legal conformity; forest planning and general forestry practice; forests and landscape; forests and biodiversity; forests and water; forests and climate change; forests and soils; and

grants from woodland grant schemes. Forestry Commission data, (cited by Yeomans and Hemery, 2010) indicated that 265,000 ha of the 914,000 ha of non–Forestry Commission woodland in England receives management grants.

Further information can be derived from the uptake of forest certification schemes (though it is noted from experts that only a minority of forest owners/managers seek certification). While climate change considerations have been added to standards, stakeholders interviewed anticipate these to become mainstream within schemes. In 2010, these schemes covered all of the public forest estate (0.81 million ha) and about 24% (0.48 million ha) of other forests. Around 45% of UK woodland and 68% of total timber production is covered by a certification scheme (Forestry Commission, 2011a). Of this, 87% of harvested conifer timber is certified; however a large proportion of small privately-owned woodland is not under the scheme.

Several studies have concluded that the proportion of forest owned by farms, hobby owners and generally small land-owners incentivised to actively manage their land is not anticipated to change without further intervention (URS, 2012).

The overall implication of increasing forest management is that a significant proportion of the 1.3 million hectares currently undermanaged would be expected to gain some level of intervention. This has been identified by the Independent Panel on Forestry, which recommended increasing the proportion of woodland in active management from the current level (~50%) to 80% in England over the next ten years.

In turn, this should, if actions are taken effectively, increase the resilience of woodlands. In practice, implementing such management would not be justified in all woodlands. Experts advise that perhaps 10% could be left un-managed (i.e. non-intervention woodland).

Enablers

The **UK Forestry Standard** (Forestry Commission, 2011a) includes a number of adaptation actions in its evidence-based standards. The requirements and guidelines in the Standard are generally implemented in all certified forests; they are also a requirement for grants etc. The UKFS now includes measures to respond to specific climate change related risks.

The Forestry Commission and Northern Ireland Forest Service provide **support to land-owners, managers, businesses and communities** through advice, communications, grants and regulation (FCE, 2012). However, the level of this

forests and people. For each element, legal requirements and good forestry practice requirements are identified, and sustainable forest management is demonstrated by full compliance with both sets of requirements. There are about 90 requirements in total, of which about a third are legal requirements" (Quine *et al.,* 2011).

advice is limited: 45 woodland officers are tasked with supporting 60,000 owners in England (FCE, 2012). There are other forms of extension support (e.g. the website www.myforest.org.uk), however according to stakeholders, their application is limited and initiatives are poorly integrated.

Current **market drivers** of change **and investment may encourage more active management.** Higher prices of firewood and concerns of value at risk from currrent pests and pathogens, such as red band needle blight, provide a greater incentive to adapt as owners/managers become more aware of the potential revenue from their woodlands.

The likelihood of more active management is strong where impacts of **weather events are already well-understood**. This includes some of the upland areas, which experience regular storms.

To respond to specific risks such as wildfires**, various groups have been established** such as the England & Wales Wildfire Forum and Scottish Forum, who are responsible for setting direction and partnerships. Several wildfire groups have also become established at a more local level in England and Scotland and are emerging in Wales. Such groups ensure there is closer engagement between land managers and fire and rescue services as well as local authorities and regulators.

Barriers

Several interviewees have described the barriers for managing forests in terms of 'bureaucratic burden'. For example, where more than 5 m^3 is being felled in a calendar quarter, requirements can often involve engagement with expert advisors, local authorities, contractors, and the Forestry Commission. However, it was noted by the Forestry Commission that while the whole process takes about a month, the burden of effort is increasingly on the Forestry Commission.

While there are demands by retailers and consumers in specific markets for certified timber, the **costs of certification** can be seen to be larger than the benefits. As a result, adoption of schemes is currently concentrated in larger forest holdings focusing on specific timber markets (Yeomans and Hemery, 2010). It is noted that efforts are being made to broaden the appeal of these certification initiatives. For instance, for the purposes of demonstrating biomass sustainability for government (and other) contracts, the UKFS can be used as an important source of evidence.

Motivation for active management is limited as **benefits from some actions implemented now will only be realised in 50-100 years' time** (FCE, 2012). The motivation for management will depend on specific objectives. (For example, Urquart (2009) has assessed the motivation for small woodland owners in England.) [41]

Limited **awareness of changes to forest management guidelines** that have been made in response to climate change is a further barrier. Experts have mentioned topics such as implications of increased run-off following clear-felling based on likelihood of wetter ground.

Costs of management can be high and owners may require professional advice and support (Read *et al.,* 2009b); Lawrence *et al.,* 2010). Furthermore, costs in the value chain (e.g. haulage costs) are also high (URS, 2012). However, it is noted that a focus on wood-fuel provision (e.g. Forestry Commission, 2007) and increases in timber prices are an enabler for improving management.

Forestry policy can change more rapidly than implementation of management plans, resulting in a lack of continuity (NEA, 2011). As stated in Yeomans and Hemery (2010): "the changes to woodland grants and support are equivalent to a farmer having to review the choice of crop about every three weeks".

Incentives to encourage proactive management of water resources are limited. While there are some initiatives where the role of forests (e.g. in terms of flood and water quality management) has been demonstrated, these are not widespread. However, it is noted that the current phase of the EWGS woodland creation grant includes targeted payment of an additional contribution (£2000 per hectare) for the delivery of water management objectives. The ECR report, 'Natural Environment Theme: Natural Flood Management' discusses underlying factors in further detail; the analysis in this report indicates that in many cases this may not be sufficient to ensure widespread adoption.

Effectiveness of measures

The development and implementation of management plans are essential to meet management objectives, such as creating mixed age and mixed species stands; these interventions are likely to increase stand resilience.

Furthermore, the production of forest management plans can support adaptive management of woodlands. For example, planning may limit the damage caused

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[41] Urquart (2009) determined private woodland owners are motivated by a range of objectives. He identifies:

Individualists (8% of sample woodland): Strong sense of ownership and privacy. Reluctant to engage with public bodies and are against public access; least likely to apply for a woodland management grant.
Multi-functional owners (37%): Motivated by multiple objectives, including amenity, conservation and financial return, alongside personal enjoyment. Pragmatic and often entrepreneurial; most likely to apply for a grant.
Private consumers (23%): Extract wood products (wood logs/poles etc.) for own use.
Conservationists (3%): Maintain woodland as a nature reserve and oppose recreational access.
Investors (18%): Financially-oriented and likely to carry out timber production or other profit-making activity.
Amenity owners (11%): Favour public access and public amenity.

by extreme events such as gales or pest outbreaks (UKFS, 2011). Beyond these generic effects, there are also the specific effects of forest management on water resources, fires and, pests and pathogens, which are discussed below.

Effects on water resources (split by ecosystem services)

Forest management influences the capacity of forest infrastructure to deal with heavier rainfall through the specification of culverts, drains, roads, paths and reservoirs (as well as some second order issues associated with water quality).

While there are guidelines for specific infrastructure, the evidence-base for effects of specific measures in response to climate change is limited. In the absence of better evidence, guidelines have used a precautionary approach, potentially leading to over-engineering. One expert gave examples of where culvert size was doubled to cope with a 20% increase in run-off in order to reduce the risk of wash-out and related issues.

Effect of wildfire management measures

Forest design plans will increasingly take into account the management of wildfires (Read *et al.,* 2009a). Following discussion with stakeholders, it is anticipated that these measures will be effective in controlling smaller fires. However, larger fires may not be controllable.

The management of vegetation fuels is seen as a critical factor, in addition to the need to raise awareness to the public and policy makers. The management of some habitats that are adjacent to forests and woodlands may not be adapted to a climate where wildfire is more common, causing an increased indirect risk.

One expert considered the current effectiveness of prevention measures to be dependent on the presence of wildfire plans, although such plans have tended to be developed where risks are greater (e.g. moorlands). At present, the existence of fire plans has been described as patchy, although some areas, such as the Peak District and the New Forest, have very good coverage. In others, however, fire plans cover less than 20% of the forest area.

The expert also noted that wildfire suppression is considered to be effective for small fires. This capability is supported by the efforts by the Fire and Rescue Services and land managers to up-skill and make preparations. However, given the nature of the risk, where years with widespread occurrence of fires may be several years apart, there is a risk that this capacity can reduce over time given other competing pressures for resources.

Further factors influencing the effectiveness of management measures for wildfires are the potential conflicts with management of other impacts. For instance, the requirement for fire breaks can be at odds with the drive for connectivity to meet biodiversity objectives; this is discussed in the next section.

Effects of pests and pathogen management measures

At a European level, the preparedness to respond to increased pest and disease risks is considered as moderate, with only a few measures recorded in existing databases. The effect of such measures depends on the nature of forest and risk involved; for instance, one expert suggested that more than 50% of productivity of a given single species mix forest could be affected by pests and pathogens, whereas this could be less than 20% in mixed forests.

The effectiveness of measures can be illustrated by the responses to current challenges. For example, red band needle blight has affected Corsican pine in the UK, resulting in a temporary planting moratorium on the species:

> "In Britain, unless the use of chemicals is adopted to suppress the disease, management will be restricted to silvicultural measures to reduce inoculum loads and the use of alternative, less susceptible species in future rotations. These are considered to be partially effective." (Brown and Webber, 2008)

In recent workshops on biosecurity, these conclusions were backed up for other major forest diseases and pests in the UK (e.g. Acute Oak Decline, *Phytophthora ramorum*, Pine Tree Lappet Moth and Oak Processionary Moth). It was also concluded that the most effective measure is reducing introductions to the UK. Once in the UK, the ability for land managers to pay for expensive containment and eradication activities that mainly benefit wider society is considered limited (Forestry Commission, 2011c).

Deer populations may be a significant pest, and can be managed to reduce populations to densities of <4-7/km^2; this is the level generally considered necessary to allow successful regeneration of some tree species. However, this requires investment and management intervention, and benefits only become notable in around 4 years (Forestry Commission, 2000). In England, the Deer Initiative is a measure supported by the Forestry Commission; alternative approaches are taken in Wales and Scotland.

Control of other pest, such as squirrels, can also be effective with management interventions.

5.4 Species and provenance selection

Species and provenance selection includes:

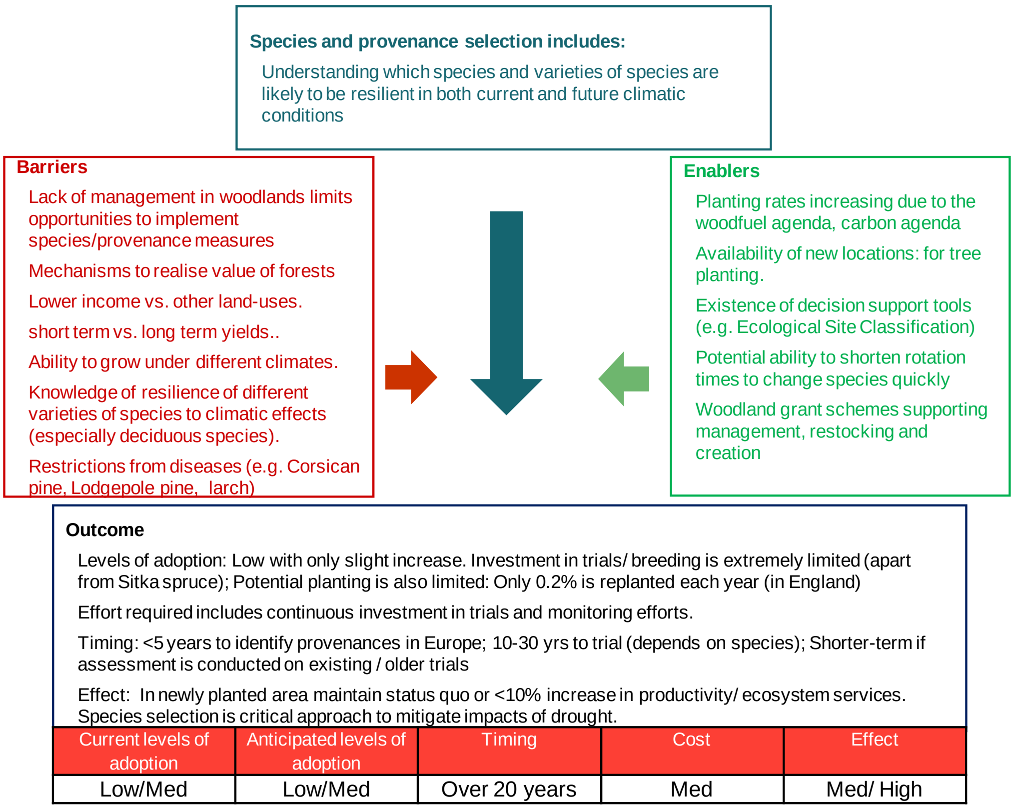
- Understanding which species and provenances are likely to be appropriate for particular objectives and resilient to current and future climatic conditions; and,
- Using more resilient species in forest planting.

Adaptation actions

When considering the introduction of new provenances and new species, more research is needed to establish which are appropriate and likely to thrive. At the same time, species selection needs to consider the overall mix and the important role of species diversification. The need for this action would be likely to be driven by the need to protect against uncertainty over the impacts of climate change, future pests and pathogens, and to facilitate a change to species better adapted to warmer, drier climates (especially in southern England) (Read *et al.*, 2009a). In areas with a high risk of wildfire, adaptation actions may include a greater focus on planting and restructuring vegetation using native and non-native species that have proven resilience to fire.

A summary of these measures is shown in **Figure 8**.

Figure 8 Summary of adaptation measures for species and provenance selection



Current levels of adoption	Anticipated levels of adoption	Timing	Cost	Effect
Low/Med	Low/Med	Over 20 years	Med	Med/ High

Source: Based on evidence from published sources and stakeholder interviews

Current/ future extent of adoption

The planting of new species or provenances will only occur in forests being restocked and therefore under management. However, it is noted in Gillam (2011) that only 57% of forest and woodland in the UK has a management plan or equivalent, and only 0.2% of forest in England is currently replanted each year (FCE, 2012).

However, many areas of British conifer forests will be due for felling in the next 10-20 years. This presents a major opportunity for adapting forests to future climate (Read *et al*, 2009a). Of the forests due for felling, a proportion uses clear-fell-restock systems, which allow for rapid introduction of new species and provenances. However, low-impact silvicultural systems, such as continuous cover forestry, may be preferred to increase resilience of specific woodlands (Forestry Commission Scotland, 2008).

Enablers:

- **Existence of decision support tools.** Tools such as the Ecological Site Classification help land managers to "select ecologically suited species to sites" (Forestry, Commission website, accessed 2012).
- **Demand for specific traits** (growth rates, resilience to spring frosts, disease resistance).

Barriers

- **Missing markets**. The substantial external benefits of forests are not likely to be realised by market investors because of market failure (e.g. for carbon sequestration and storage where there are funding opportunities available through the Woodland Carbon Code but no functional market in place). This is likely to lead to under-investment in forest creation and management in the absence of intervention.
- **Ability to increase forest-cover by land-use change**. Under current market conditions, forestry represents a lower return than other land-uses such as agriculture; there are many disincentives to plant new woodlands.
- **Trade-off between short-term versus long-term yields.** At present, commercial managers are considering new species but most are not planting with a view to climate change. Stakeholder interviews suggest that commercial managers are changing their species to protect against known pests and pathogens, as these are a more imminent threat. This focus on the short-term is a behavioural barrier to adaptation action being taken. However, there are examples of guidance on species diversification (Forestry, Commission Wales, 2010) to address both climate change and biosecurity threats. The lower productivity of some of the more resilient

species is a further disincentive to planting species better adapted to climate change.

- **Long-lived species.** Trees (especially hardwood species) may have to grow under very different climates; options are limited to species that are resilient to conditions today and to those many years in the future. In addition, variation in the climate poses limitation on suitability, (e.g. while some southern provenances may be more suited to warmer or drier summers, they may not be resilient to episodes of severe winter cold and early autumn or late spring frosts (Ray *et al.,* 2008).

- **Information failures.** Too little is known about how resilient different populations of native species are to future climatic effects (Ray *et al.,* 2008). This information barrier to adaptation suggests more research is needed, including the need to revisit and assess older experiments as well as increasing the investment in new operational trials. Enhanced and long-term ongoing monitoring is also required to track and evaluate performance of different species and provenances.

- **Missing markets.** There are a limited number of climate-resilient species which can outperform the main timber production species. In particular, replacements for Sitka spruce in areas where it is the dominant species are not currently available. 40% of commercial forest grows Sitka spruce, which is considered to be a reasonably resilient species in upland areas. However, its performance is dependent on sufficient water being available. Furthermore, past experience with other species considered resilient (e.g. Norway spruce in Northamptonshire Forest District) illustrates how a species can decline in productivity after a series of dry summers.

  The underlying evidence for commercial managers to change their planting decisions to a less productive species needs to be compelling. At the same time, species/provenances need to be available in sufficient volumes in commercial tree nurseries.

- **Asymmetric information.** Research has been undertaken on climate resilient populations/genotypes/provenances but this needs to be collated. According to stakeholders, efforts with native species also need to be extended.

- **Fragmentation of sector and scale of research.** Individual commercial owners do not have enough funding and incentive to invest in research. There is therefore a dependency on organisations such as the Forestry

Commission and NGOs such as the Future Trees Trust[42] to sustain trials and research.

Effects of measures

Collating research and understanding which populations / genotypes / provenances of species will be more resilient, as well as planting more resilient species, are seen by many stakeholders as two of the most important long-term measures to be taken.

However, there are many complexities which will need to be taken into account when assessing these measures. For instance, while provenances from warmer climates show adaptation to the longer growing season in lower latitudes, they suffer from early or late frosts when moved too far into higher latitudes (Boshier, 2007). The use of the improved QCI (Queen Charlotte Island) provenance of Sitka spruce provides a whole yield class advantage (yield class 18 to yield class 20) over unimproved varieties but can be damaged by early frosts (Ray *et al.,* 2008).

Overall, research suggests that current productivity could be maintained by selecting planting stock with an origin up to 2° latitude south of a specific site, and up to 5° south as a small component of mixed provenance stock. (Ray *et al.,* 2010). However, this is regarded by the experts consulted as a rough approximation, as there are many variables involved in determining productivity at a site for any one species.

It was also noted by stakeholders that an improved understanding will only be possible if there are sufficient assessments (e.g. multi-site planting trials) to review effects. This includes not only new trials, but also revisiting past experiments and identifying opportunities for technology transfer from other countries. Trials which are "operational" where early findings can be extracted are considered by some stakeholders to be an important aspect of this approach. This can include the use of molecular or physiological approaches to be used to test different genotypes and shorten the research and evaluation phase.

At the same time the selection of species/provenances has to consider implications for biodiversity objectives and the delivery of other ecosystem services. As a result, there is a risk of maladaptation if selection in response to a particular climate-related objective could increase exposure to another risk.

[42] http://www.futuretrees.org

5.5 Adoption of alternative silvicultural systems

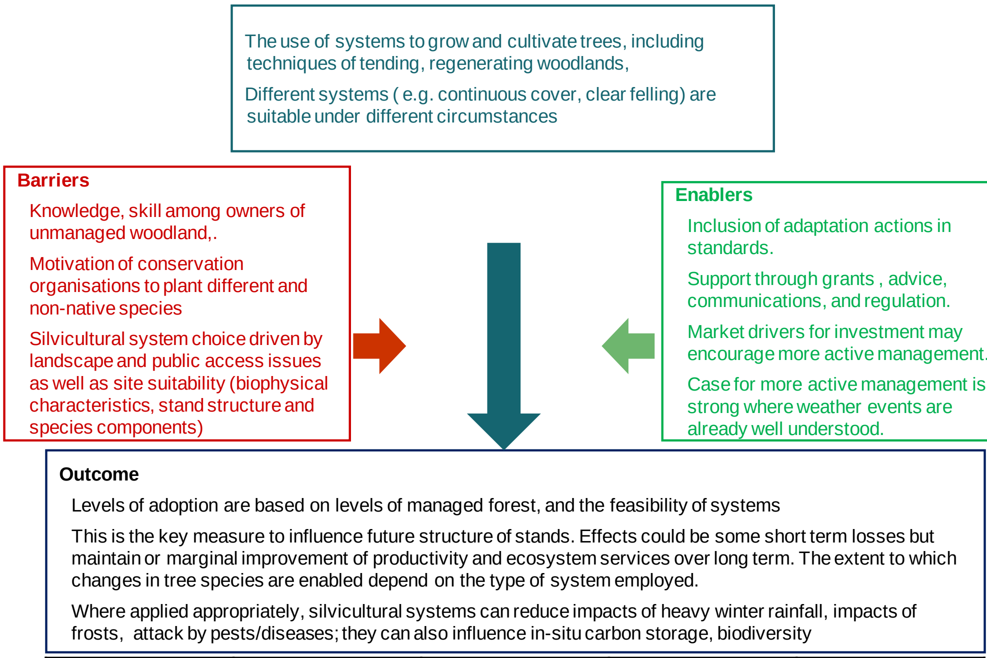
Silvicultural approaches include the *active* "growing and cultivation of trees, including techniques of tending and regenerating woodlands, and harvesting their physical products." (Forestry Commission, 2011). These can include diverse approaches such as:

- **Clearfelling** within a system of well-designed small coupes to produce different age classes within the forest;
- **Shelterwood systems** to encourage establishment at restocking, both through natural regeneration and planting; and,
- **Continuous cover selection systems** to encourage a mixture of different age classes.

Specifically, this adaptation action considers the implementation of *alternatives to large-scale clearfell systems* where suitable sites and species combinations allow. It can include augmenting natural regeneration through planting where species diversity and potential adaptability is likely to be limited. The intention is to offer advantages for regeneration and establishment, and to establish a range of stand structures over time.

A summary of the impacts of using alternative silvicultural measures is presented in **Figure 9**.

Figure 9 Summary of adaptation measures for alternative silvicultural systems



Current levels of adoption	Anticipated levels of adoption	Timing	Cost	Effect (incl. co-benefits)
Med	Med	Ongoing management	Med	High

Source: Based on evidence from published sources and stakeholder interviews

Current/ future extent of adoption

Alternative silvicultural systems are often tested by the Forestry Commission, NGOs and the research community, and thereafter adopted by forest managers. As discussed above, the proportion of forest owned by farms, hobby owners and generally small land-owners who actively manage their land is unlikely to change. The implication is that without further intervention the extent of adoption of alternative silvicultural systems would not be expected to increase substantially. However, there are a number of drivers which are expected to increase adoption of different systems. These include rising wood-fuel prices (incentivising woodland owners to bring them into management) and initiatives to increase the area of certified woodland.

Enablers

- The use of alternative silvicultural systems is included within the **UK Forestry Standard**. (Forestry Commission, 2011a).

- There are various advisory services which **support landowners, managers, businesses and communities** in their application of different silvicultural systems (FCE, 2012).
- **Stakeholder interest** in alternative silvicultural systems to manage amenity, landscape, and biodiversity.

Barriers

- Limited **adaptive capacity and incentives to replant.** Smaller owners of unmanaged woodland, such as farmers or hobby owners, may not have the knowledge, skill or desire to use different silvicultural systems or actively plant new species. Managers of planted ancient woodland sites (PAWS) are required to preserve site native species under UKFS and would not be motivated to plant different provenances and species.
- **Site constraints.** The choice of silvicultural system can be driven by landscape and public access issues as well as site suitability. However, the likelihood of successful adoption is "largely constrained by biophysical characteristics of the site, stand structure and species components and management objectives" (Forestry Commission Scotland, 2008).

Effectiveness of measures

Silvicultural systems such as Continuous Cover Forestry (CCF) can conserve the local forest canopy/environment during the regeneration phase, and can create a diverse age and stand structure; they can offer a number of benefits that may increase resilience (Stokes & Kerr, 2009). However, adopting such a system can make new species introduction more difficult (Macdonald and Gardiner, 2005).

The potential benefits of alternative silvicultural systems such as CCF are described**Error! Reference source not found.** in Stokes and Kerr (2009) who considered implications to forestry in Scotland (**Table 6**)

Table 6. Potential effects of continuous cover forestry in relation to climate change risks in Scotland.

Risk to forests in Scotland	Rating of potential impact[43]	Effect of CCF	Evidence base for judgment[44]	

[43] Impact ratings used by Stokes and Kerr (2009) include: Low – there will be an impact but it is unlikely to be significant. Medium – there will be a significant impact on a narrow range of economic, social and environmental factors on a limited area. High – there will be a significant impact on a broad range of economic, social and environmental factors on a wide area.

Primary risks				
Increased incidence of strong storms	High	Neutral-Positive	Good	
Increased incidence of heavy winter rainfall	Medium	Positive	Moderate	
Changing growth rates due to increased CO_2	Medium	Neutral	Good	
Increased temperatures and incidence of drought	Medium	Unknown	Poor	
Reduced incidence and changed timing of frosts	Low	Positive	Good	
Secondary risks				
Attack by pests and diseases - general	High	Positive	Moderate	
Pine weevil	High	Positive	Moderate	
Green spruce aphid	High	Unknown	Moderate	
Heterobasidion annosum	High	Neutral	Poor	
Red band needle blight	High	Neutral	Poor	
Implications for *in-situ* carbon storage	High	Positive	Moderate	
Impact on biodiversity	High	Positive	Good	
Changing tree species suitability	Medium	Negative	Moderate	
Increased deer damage	Medium	Neutral	Poor	
Changes in timber quality	Medium	Neutral	Moderate	
Changes in weed competition	Medium	Unknown	Poor	
Changing phenology of natural regeneration	Low	Unknown	Poor	
Forest fires	Low	Negative	Moderate	

Source: Stokes and Kerr (2009).

[44] Evidence-based ratings used by Stokes and Kerr (2009) include: Poor - small amount of evidence, poor understanding of factors. Moderate - reasonable evidence-base but no direct studies of CCF vs. even-aged management. Good - sound evidence-base including scientific studies of CCF vs. even-aged management.

Adaptation actions

5.6 Woodland creation and landscape-scale management

Landscape or catchment-scale measures involve a range of interventions across multiple forests, for example:

- **Landscape scale approaches to nature conservation.** This includes woodland creation to form larger forested areas, active management of biodiversity, and reduction of fragmentation.

- **Catchment water management** to address flood and water quality issues. This is primarily through woodland creation (and, in some cases, woodland removal).

- There are also other measures related to wildfire planning and management (e.g. fragmenting high risk habitats), deer management and managing environmental quality (and heat effects) in urban areas.

The effects of these measures are summarised in Figure 10.

Figure 10 Summary of adaptation measures for landscape-scale management

Landscape scale approaches to nature conservation including woodland creation

Catchment water management to address flood and water quality issues. This is primarily through woodland creation

Measures related to wildfire planning and management, deer management, and planting in urban areas.

Barriers

- Ownership boundaries straddle catchments
- Lack of mechanisms to capture value of increasing forest cover
- Co-ordination between forestry and other land-uses (incl. down-stream.
- Interventions can benefit some species at the expense of others.

Enablers

- Regulations (e.g. Water Framework Directive) encourages activities at this scale
- Examples of successful initiatives (e.g. Pontbren, Slowing the Flow) and emerging mechanisms for Payment of Ecosystem Services (PES)
- Requirements for landscape planning for new woodland in UK Forestry Standard

Outcome

Levels of adoption: Several initiatives demonstrate potential which could increase

Effect: Important effects to address specific issues; likely overall increase in resilience

	Current levels of adoption	Anticipated levels of adoption	Timing to observe effect	Cost	Effect (incl. co-benefits)
Catchment management	Possibly <25% of current forests	Could be 25-50% depending on location	Over ten years	High (if assuming land-use change)	Could affect flood-flows by 10-20% Water yield could +/- 2-10% based on 10-50% change in forest cover
Landscape management					Significant increase in resilience in some species / no impact on others Some reduction in edge-effects

Source: Based on evidence from published sources and stakeholder interviews

Current/ future extent:

As noted in Table 2, The current level of woodland creation was 8,200 ha/yr in 2011; the aspirational annual forest cover growth of all countries combined based on announcements made over the last six years was 17,350 ha /year

The use of measures at the landscape scale is fairly common. The Forestry Commission has published and implemented guidelines on landscape design for many years. This has expanded beyond issues such as visual impacts, to consider the catchment as a suitable geographic unit in which to plan forests.

Furthermore, there are number of initiatives which can serve as a platform for landscape-scale design and management. These include: EA/Defra approaches for implementing the Water Framework Directive, the Nature Improvement Areas mentioned within the Natural Environment White Paper (UK Government, 2011) and the Deer Initiative in England. Additionally, there are a number of initiatives in the UK and internationally to identify and develop mechanisms to establish payment for ecosystem services that could be an important enabler (e.g. Ecosystem Markets Taskforce, 2012).

Adaptation actions

According to expert interviews, 25% to 50% of land could currently be managed according to this approach; this would primarily be in public forests (which could be as high as 75% of land managed).

However, current and future adoption will vary substantially by location: in the uplands it could become the norm even among private owners (who typically are responsible for larger forests). Implementation of these types of interventions in the lowlands is likely to remain lower (Nisbet *et al.,* 2011) due to the large number of actors involved.

Enablers

Regulations such as the Water Framework Directive encourage organisations/individuals to work at this scale; furthermore pilot catchments to achieve landscape scale water management benefits have been established. However, according to experts, some of the newer measures which are being implemented (e.g. thresholds for felling in sensitive catchments) flag-up difficulties of co-ordination where there are multiple owners within a catchment. Similarly, guidelines for forest planning encourage landscape-scale considerations in new woodlands (Forestry Commission, 2011b).

There are **several examples of successful initiatives** working at this scale. The impacts of initiatives such as Pontbren (Pontbren farmers, 2012) on biodiversity, flood alleviation and carbon have been well-documented. Similarly, there are initiatives based around fire groups to address wildfires (e.g. South East of England Regional Wildfire Group & Home Counties Operational Wildfire Group, 2010).

Barriers

Forest ownership and boundaries frequently straddle catchments and therefore there are difficulties in co-ordinating actions. This will be particularly important in lowlands, where catchments are larger and there are a larger number of owners involved.

Co-ordination is further complicated by the barriers in terms of interface between forests and adjacent land-uses/users.

Market failure owing to a **lack of mechanisms** to capture the external benefits of increasing forest cover (e.g. for riparian corridors, shelterbelts, expansion of forest fragments, development of corridors, etc.). In many cases, alternative land-uses yield higher returns. However, it is noted by several experts that these barriers are being addressed through initiatives, including those started by the EA, Woodland Trust, EWGS, as well as the Ecosystem Markets Taskforce. Other organisations such as United Utilities are also looking at using woodland creation to improve water quality (United Utilities, accessed 2012).

Multiple management objectives: landscape level interventions can benefit some species at the expense of others. For instance, wildlife corridors can play an important role in increasing biodiversity but can also act as migration corridors for pests and pathogens.

Poor **understanding of the impacts of wildfire** upon the UK's habitats at present and in the future and a need for **cross government department and sector working** to address key wildfire challenges at the landscape scale.

Effects of landscape-level measures

For this section, the effects are considered in terms of the some of the different measures introduced above.

Catchment management

The effects of forest management (or lack of management) on **water quality** in existing woodland is varied: there are examples of impacts on diffuse pollution, water resources, flood alleviation, and riparian management (Nisbet *et al.,* 2011). The benefits of introducing management will vary by location, depending on whether forest management is impacting surface water resources or groundwater, and their relative importance in any location.

Forests as a measure to alleviate the **impacts of flooding** is discussed in further detail in the ECR report in the Natural Environment Theme, Natural Flood Management. Overall, effectiveness of measures is strongly related to the scale being considered. For instance, catchment management can focus on a specific stream or a whole river basin. For a headwater, or small catchment scale, experts consider measures to be extremely effective; for catchments such as the Thames, the ability to influence flooding risk is very small, as forest covers less than 10% of the catchment.

The effect of measures can only be determined by specific issues; for example forest management, in combination with drain realignment, could reduce flood flows by 10-20%. In the urban environment, some studies indicate that trees can reduce surface water runoff by up to 60% compared to asphalt (Armson *et al.,* 2011). This increases the possibility of infiltration and the ability of engineered drains to take away any excess water.

The effects of forest design planning on **water availability** are also important. For instance, for every 10% of upland catchment covered by mature conifers, annual water yield can be reduced by 1-2% (Nisbet, 2005). However, this relationship cannot be applied to drier lowland areas where a 100% cover of conifer could reduce groundwater recharge by up to 70% (Nisbet, 2005). Local geology, climate and tree species are all critical determinants of water availability and thus of the effect of any adaptation measure. For example, Nisbet (2005) notes that limited difference in groundwater recharge was observed between broadleaf woodland and permanent pasture on chalk.

Adaptation actions

Nature conservation

As part of a landscape level approach, increasing habitat size and linkages between different patches is critical for biodiversity (Mitchell *et al.,* 2007). The concept of forest design to increase connectivity is well-accepted. While there is considerable evidence that many species can move across corridors, these benefits are limited for some groups (Mitchell *et al.,* (2007)

The climate change risks described in Section 3 include extreme weather events, which can cause localised population declines as well as gradual change. The implication of the measures described in this report will depend on the type of landscape being considered (Read *et al.,* 2009b):

- Interventions are likely to have a small effect if starting with landscapes with low permeability, as greater effort is required to connect existing habitat.

- For landscapes with intermediate levels of permeability, initiatives could result in the creation of a range of semi-natural habitats allowing many different species to move in and, through the wooded components of the landscape, helping to conserve woodland biodiversity.

- For landscapes with high permeability and extensive woodland cover, the influence of measures is low and the ability to adapt is already high.

A key aspect to consider is average patch size. Large patch sizes provide a broader range of habitats for species to find suitable conditions, which will enable them to survive the changing climate. They also support larger populations which are likely to be more genetically diverse, more resilient and able to adapt better to the changing conditions. At present, broadleaf woodland has an average patch size of 9.5 ha, with median patch size of 3.9 ha (HMSO, 2010). Targeting woodland creation to expand existing high value woodland habitats (as, for example, in the EWGS-funded Jigsaw scheme on the Isle of Wight) would represent an adaptation measure (Quine and Watts, 2009).

The Lawton review suggested that it is better to "enhance the chance of species to stay in their climate envelope by small-scale, local movements rather than long distance dispersal." (HMSO, 2010). However a further detailed assessment of changes to forest cover and size/location of habitat patches in the context of climate change would be needed to develop an appropriate response. This could also play an important role in setting priorities for initiatives such as the Environment Bank, Nature Improvement Areas and biodiversity offsetting. It is beyond the scope of this report to provide a cost benefit analysis of such options.

Wildfire management

When using landscape-level measures, consideration should be given to reducing the scale and impact of wildfire. Ideally, this should be achieved by creating smaller areas, as well as ensuring that forest management is financially sustainable in the long-term to reduce fuel loading and so reduce the incidence of significant wildfires.

Heat management

The positive impacts of green-cover are illustrated by the modelling studies by Handley and Carter (2006). They found that adding 10% green cover keeps Maximum Surface Temperatures (MST) in high-density residential areas (Manchester) at or below 1961-1990 baseline up to the 2080s.

Table 7. Maximum Surface Temperature (MST) of green cover in high density housing (evaporating cover 31%)

MST with no change in green cover		MST with 10% green cover removed		MST with 10% green cover added	
1961-1990	2080s	1961-1990	2080s	1961-1990	2080s
BASE: 27.9 °C	+1.7 °C to +3.7°C	n/a	+7 °C to +8.2°C	-2.2 °C	-0.7 °C to +1.2°C

Source: Gill *et al.*, (2007)

The role of forestry and other green infrastructure as a cooling measure is discussed in more detail in the ECR Buildings and Infrastructure theme: Overheating in Residential Housing report.

5.7 Cross-sectoral links

As discussed in the adaptive capacity section, the forestry sector has close linkages to agriculture and other sectors influencing land-use. There are a number of critical links between specific adaptation actions described above which need to be appreciated:

- **Forest-level measures:** The development of infrastructure for forests could interact with other transport and water management infrastructure being developed in other sectors. The management of wildfires, flooding and extreme weather events will need to involve interaction with health, business and other sectors.

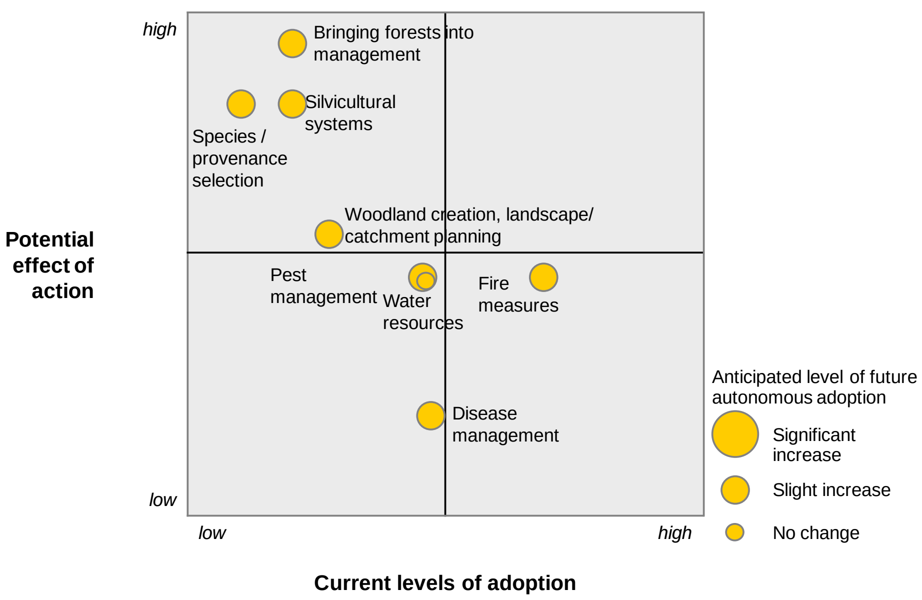
- **Stand-level measures.** There could be some overlap with the underlying science for understanding pests and pathogens and underlying plant physiology with sectors such as agriculture.

- **Landscape-level measures** can only be considered as part of a wider consideration of land-use and complementary/competing demands from other sectors, including agriculture, housing, infrastructure, business and services, among others.

5.8 Extent of adaptation

It is important to gain a general view of the current and expected degree of effective adaptation so that key barriers can be identified and addressed through intervention by government or other bodies. This is shown in **Figure 11.** This provides a simplified summary, based on the evidence presented in this Section and stakeholder discussions.

Figure 11: Summary of current and anticipated effects of different adaptation actions in privately owned woodland



Source: Based on the evidence in this report and stakeholders
Note: Scales are qualitative and relative to the sectors included. The **current levels of adoption** include forest management decisions that are infrequent (such species selection) to common practices. **Effectiveness** varies from limited scope due to impact of measure, time frames or effort involved. The position of each measure is based on the classification within main text in this chapter and, given the factors discussed above, could vary considerably depending on type of forest manager/owner. If this diagram were repeated for the Public Forest Estate, the current levels of adoption would be considerably higher, but in many cases the effect of the action may not be substantively different.

The top right corner of the figure shows those actions where adaptation is working well. There may be areas where the adaptation is maladaptive but, generally and in the short-term, these actions are effective and widespread. Those actions in the top left corner are effective but not widespread, suggesting that barriers to action exist. The actions in the bottom right corner are widespread yet not effective, either because they are driven by other objectives, they are easy actions, or they may be maladaptive. Those actions in the bottom left corner are neither effective nor widespread.

It is important to note that if adaptation is not necessarily effective, it can lead to maladaptation if action is taken without full consideration of the longer term risks. Furthermore, there is an optimal level of adaptation, beyond which the costs of measures exceed the probable value of the benefits.

There are a number of key points to conclude from this assessment:

- **Bringing woodlands into management** is one of the important measures to adapt to climate change
- **Species/provenance selection and choice of silvicultural systems** together have an important effect **in building resilience** to climate change at a stand level. However, efforts in both areas could be substantially increased.
- **Landscape/catchment planning** can make an important contribution to address site-specific issues. Underpinning these measures in many cases is woodland creation.
- Other interventions are important for managing specific issues such as fire, pests and pathogens. However, given the nature of these risks their effectiveness is variable.

5.9 Common barriers to effective adaptation

Where actions in **Figure 11** are in the top-left quadrant, this could indicate that there are barriers to the implementation of effective actions. Likewise, barriers could hinder the effectiveness of actions meaning they are in the bottom-right quadrant.

The enablers and barriers to actions have been discussed in detail above; the following assessment highlights those that are common across several actions. It uses the classification described in Section 2: market failures, policy failures, behavioural failures and governance failures.

5.9.1 Market failures

Externalities can be identified in several forms:

- **Notable proportions of forest are not subject to active management**. In such forests there is little, if any, ability to ensure they are adapted to future climate change. Only 57% (48% in England) of forest and woodland has a management plan or equivalent (Gillam, 2011).

- **Where forests are subject to active management, the incentives for forest managers to protect ecosystem services may be limited by the lack of private return from doing so. Returns may also not be realised within a feasible time-frame, owing to the low activity levels caused by the very long rotation periods of typically 40 to 50 years** (and up to hundreds of years for some hardwoods) and the annual restocking rate of only 0.2% in England (FCE, 2012). The benefits of species or provenance selection actions may therefore take many decades to be realised.

Information failures are evident from a range of perspectives:

- **Forest managers are often not aware of climate-resilient provenances and species to meet long-term timber production needs and ecosystem services delivery**. Availability of climate resilient species and provenances means projected climate change is not consistently reflected in new planting decisions. In addition, there are few climate-resilient tree species presently available from UK nurseries that could outperform existing species.

- **Little evidence is available on the costs and benefits of adaptation actions** and the conditions under which they are likely to be effective. The analysis in this report illustrates the potential effectiveness of action under particular assumptions but it is not accost-benefit analysis.

5.9.2 Policy failures

There are currently **no formal markets**[45] **to allow the economic benefits of enhancing or protecting biodiversity**, **sequestering carbon or other ecosystem service benefits, to be realised** by forest owners. Policy addresses this, in part, through grants. However, the current level of grants available is not likely to be sufficient to increase forest land-cover where land competes with more economically productive uses, such as agriculture.

5.9.3 Behavioural constraints

'Short sightedness': as noted above, at present commercial managers are considering new species but most are not planting with a view to climate change.

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45 However, less formal payments for carbon sequestration in woodland creation projects can be realised through certification to the Woodland Carbon Code.

Stakeholder interviews have suggested that commercial managers are changing their species to protect against known pests and pathogens, as these are a more imminent threat. This focus on the short-term is a behavioural barrier to adaptation action being taken. However, it is noted that there are examples of guidance on species diversification (Forestry Commission Wales, 2010) to address both climate change and biosecurity threats. A further disincentive to changing species is that many species which may be more resilient to climate change are less productive.

5.9.4 Governance barriers

Co-ordination barriers: Forest ownership and boundaries straddle the catchment and therefore there are difficulties in co-ordinating actions. This will be particularly important in lowlands where catchments are larger and there are a larger number of owners involved.

6 Case for intervention

6.1 Introduction

This Section presents the case for intervention by first discussion adaptive management as an effective approach to developing adaptation strategy and then illustrating 'what if?' scenarios to show the potential effectiveness of several adaptation actions. Recommended interventions to address barriers to effective adaptation are then presented.

6.2 Adaptive management

There are different types of uncertainty regarding future impacts of climate change on the UK (see Annex 2) and, in particular, over how they are expected to impact at the local level, and when. This should not be taken as a reason not to act.

These uncertainties are particularly problematic for planning management options with long life-times, as such investments are difficult to reverse. If forecasts are incorrectly made today, the action can lead to maladaptation or unnecessary costs (Reeder and Ranger, 2011). Adaptation decisions must therefore be resilient to a rapidly changing and uncertain climate (Hall, 2007).

In this analysis, **adaptive management** is illustrated through **adaptation roadmaps** as a pragmatic and effective way to facilitate decision-making.

This approach allows **flexibility to be incorporated into adaptation measures from the start,** where possible, (e.g. by using measures that are suitable over a broad range of possible future climates or by designing the adaptation measure so it can be adjusted over time: Fankhauser *et al.,* 1999). **Flexibility is also incorporated into the overall adaptation strategy** by sequencing the adaptation, so that the system adapts to climate over time, but options are left open to deal with a range of possible future scenarios.

Adaptive management encourages decision-makers to pose 'what if' questions and take an approach whereby decisions are made over time to continuously adapt, while maintaining as much flexibility as possible for future options. The essence of the approach is to be clear on the direction of travel, the vision for the desired outcomes or the management/goals, and the uncertainties about how to achieve these outcomes (Murray & Marmorek, 2004). Having chosen a course of action, decisions are made with learning, reviewing and modifying actions, as appropriate, along the way.

6.2.1 Adaptation roadmaps

The adaptation roadmaps developed here are intended to show "packages" of measures that can be iterated over time. to address the overarching question considered in this report (Section 2). The overarching question includes a number of different climate risks, many of which will be addressed by the same adaptation measures. As a result, the roadmap illustrated below represents potential responses to each in turn.

This report has not set out a detailed pathway, such as the Thames Estuary 2100 Report Project, because the "known thresholds" (Reeder and Ranger, 2011) for climate change impacts on forest production have not been assessed for this report. For the forestry sector, given the long rotation periods of trees, an important piece of analysis that should be undertaken in future is the development of a process to identify when a particular decision needs to be made. **However, for this report, the roadmaps are focused on building adaptive capacity in the sector, improving ability to appraise and evaluate interventions and increasing species and structural diversity in forests (and associated open habitats).**

Prioritising adaptation options given both the uncertainty and the long time span of forestry leads to a focus on those options that are:

- **'No-regrets'**: those actions for which there would be net benefits, irrespective of climate change. This may include building adaptive capacity or enhancing climate change impacts knowledge, or increasing the area of forest in management;

- **Win wins**: actions that are able to contribute to wider objectives along with climate change adaptation, (e.g. bringing forests into management or implementing actions which protect or enhance ecosystem services; further examples include species diversification which addresses biosecurity issues as well as climate change).

- **Strategic options with long lead-times** (e.g. species or genotype trials and tree breeding). These measures will have little benefit in the short-term, but will be important in ensuring there is an appropriate mix of species and provenances for trees planted in several decades time. They also include measures which can lead to transformational change within the sector (e.g. mechanisms to monetise a broader range of ecosystem services).

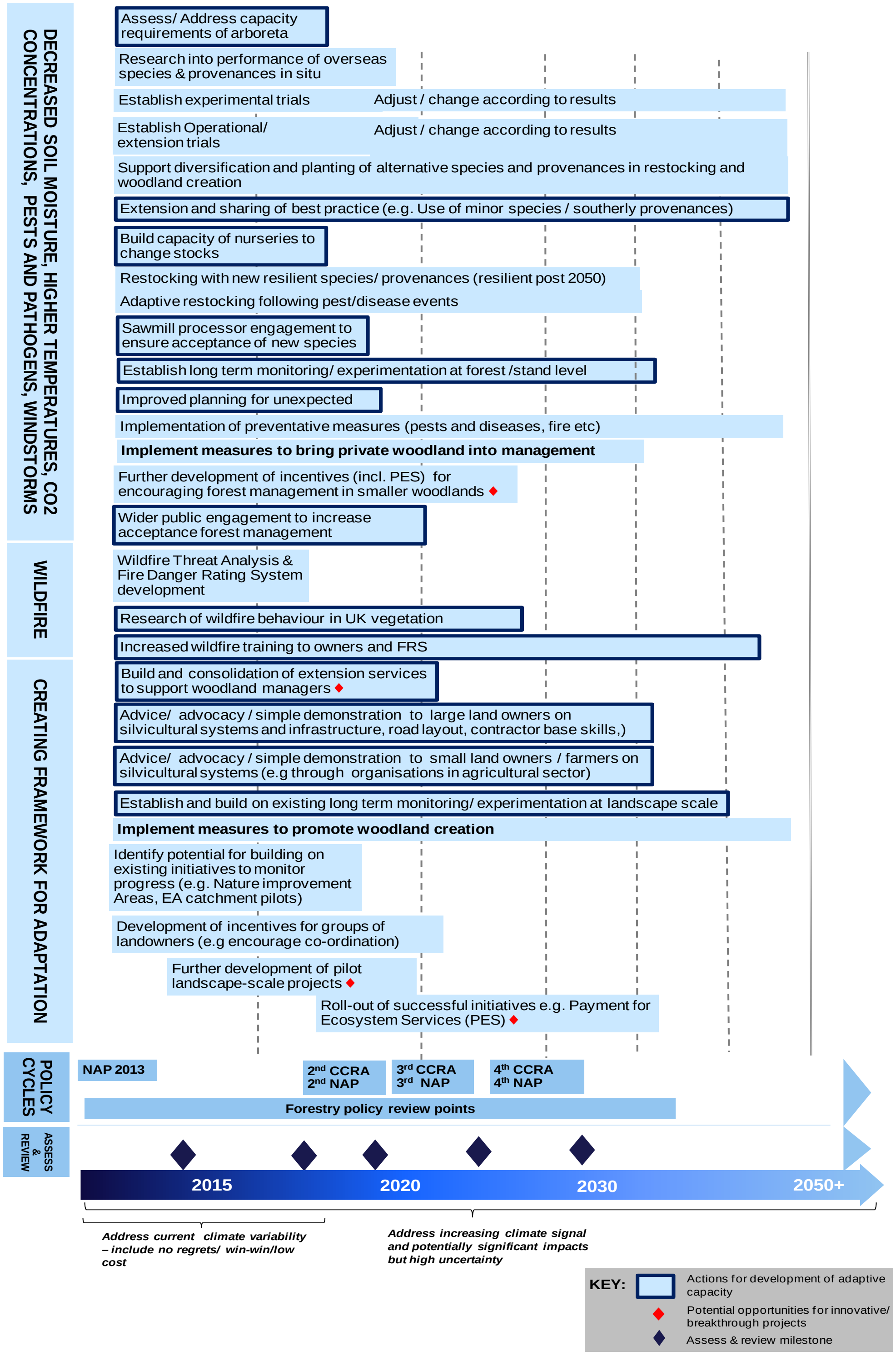
This focus aims to ensure that actions taken will not be maladaptive if climate change progresses at a rate different from expected today, and to review unintended consequences.

It should also be recognised that any action chosen should be taken with the engagement of stakeholders with reference to available data to allow progress and emerging outcomes to be monitored and reviewed.

The illustrative roadmaps in **Figure 12** cover potential actions to address threats and opportunities for forestry and associated ecosystem service delivery as discussed in the 'what-if?' scenarios below. The roadmaps are not intended to be comprehensive or exhaustive, as there are many other roadmaps to consider. Instead, **Figure 12** is intended to be an indicative illustration of some of the actions that are likely to be effective up to the 2050s and when key review points should occur.

The measures in the figure fall within the categories of actions discussed in Section 5, and have been identified from published research and stakeholder evidence. It is noted that further engagement will be required to confirm and validate the more precise timing and nature of measures required.

Figure 12: Summary of selected illustrative adaptation roadmaps



Source: Based on the evidence presented in this report, including stakeholders.

As shown, many of the actions in the short-term relate to building adaptive capacity to ensure that the future ability of those in the sector to adapt is enhanced, (e.g. demonstration or extension activities). In addition there are a number of ongoing activities to respond to risks described in the report (e.g. planting alternative species and more southerly provenances, bringing woodland into management, etc.)

Actions in the short-term also includes a number of evidence-building activities (e.g. research into wildfire behaviour) to support decision-making. This creates a framework for adaptation. It should be noted, however, that other adaptation actions will be happening at the same time and include a number of **no-regrets options, such as:**

- Identifying potential for building on existing initiatives to monitor progress;
- Analysing wildfire threat and establishing a fire danger rating system; and,
- Understanding the comparative performance of different provenances.

Actions in the **medium term** are in two parts – those that need to be taken because if they are not, irreversible decisions may be made which could lead to maladapted outcomes. These may often involve long decision time-frames (e.g. species selection and diversification of woodlands). Other medium-term actions may not require early action (e.g. adaptive planting following pest/disease outbreaks occurring in the future).

Following research activities, development of best practice actions and implementation of research findings will occur, based on the outcomes of the research. These processes are iterative, allowing flexibility in decision-making. These include measures in response to wildfire research, ecosystem function amongst others. It should be noted that in many cases these actions are already occurring.

Figure 12 also shows that some actions are likely to be **innovative or breakthrough initiatives**. These are more transformational in nature rather than incremental changes to current processes or decisions. Examples could include further development and implementation of landscape/catchment scale initiatives as well as mechanisms for payment for ecosystem services.

Interdependencies

There are important **inter-dependencies** across the options in the roadmaps. For example, many of the options (e.g. pest and pathogen management) rely on capacity building (e.g. supporting small-scale forest owners develop management plans) and the framework for adaptation. The adaptation roadmaps focus on the impacts of drought, pests and pathogens, changing rainfall and temperature, in one sector, but there are many connections to other sectors that need to be considered in order to lead to effective adaptation. For example, the role of forestry in catchment management needs to be closely co-ordinated with those involved in flood management and managing water quality.

Review points

The adaptation roadmaps incorporate review points, where policy and practice can be assessed and evaluated in the light of new developments, new information and emerging understanding on climate risks and research outputs. The review points are designed to coincide with policy cycles (e.g. of the NAP and CCRA) as well as at points where adaptation actions should be maturing. These frequent review points will allow roadmaps to be developed **iteratively** and with consideration of inter-dependencies and linkages across options.

At each review point, the options must be considered as portfolios of short-term, medium-term and long-term responses. The review points will also allow consideration of the options in the context of developing evidence on evolving climate risks. There may be additional review points where major review and consultation is required, if there is an extreme event (e.g. emergence of a new pathogen) or if the upper end of climate projections and uncertainty ranges were approached.

6.2.2 Exploring the potential impacts of adaptation through 'what if?' analysis

The roadmaps discussed above do not provide an indication of the extent to which the impacts of those threats could be mitigated, or opportunities maximised. In order to capture this, a series of illustrative 'what if?' scenarios have been explored.

The purpose of these scenarios is to draw on available evidence and expert advice to illustrate the potential scale of relative effects where particular adaptation actions are taken. Scenarios indicate potential impacts under particular assumptions, noting that it is not possible to say how many forest owners would be expected to adopt particular actions.

It is important to note that more detailed analysis would be required to develop accurate estimates of the scale of the effects.

6.2.3 Scenarios explored

The range of scenarios is broad, though is not an exhaustive set because data and information limitations mean that at this stage such analysis has not been possible in the time available. It should be noted that 'what-if?' scenarios are, by definition, not intended to be interpreted as projections and, in some cases, describe extreme situations. They are dependent on the underlying assumptions.

Scenarios explored relate to:

- Managing the impacts of climate change on species suitability through (i) re-stocking with species projected to be a higher yield class by the 2050s as a result of climate change; and (ii) undertaking research to allow climate resilient populations and genotypes to be identified and used to re-stock forests.

- Reducing exposure to the uncertain potential impacts of pests and pathogens by diversifying species to (i) lower the area planted with Sitka spruce to mitigate against the impacts of a pest, such as the green spruce aphid, which lowers potential production; and, (ii) reduce the area planted with Sitka spruce to mitigate against a pathogen which would otherwise cause the sanitary felling of the entire forest affected.

6.2.4 Managing changes in climate suitability for different species

Scenario 1: What if re-stocking takes place with those species projected to have the highest yield in the 2050s and 2080s in the presence of climate change? Species that are expected to be particularly susceptible to pests and pathogens are assumed not to be used for re-stocking.

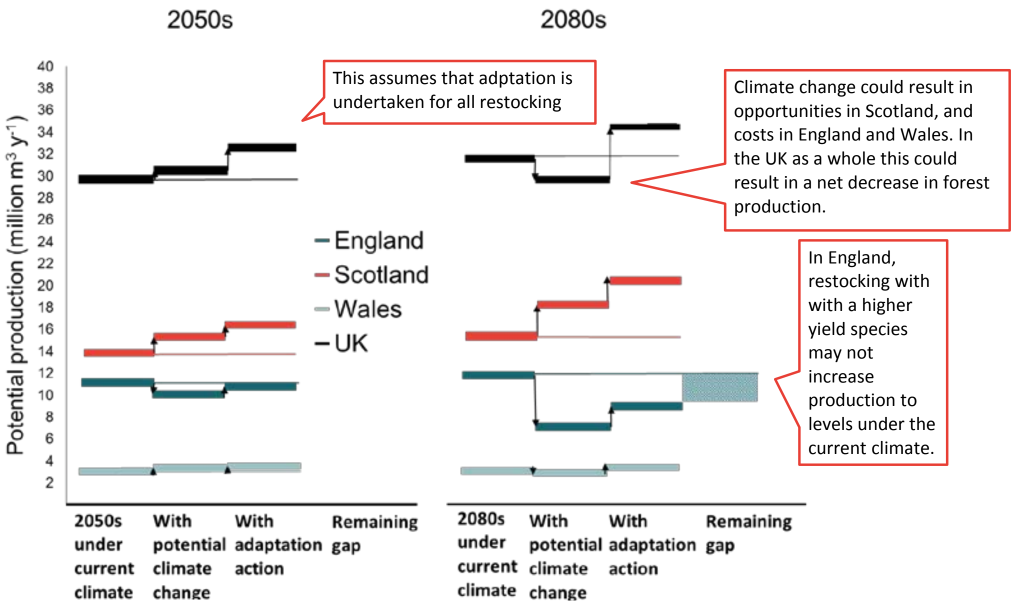
The gradual change in temperature and soil moisture is projected to affect the suitability of species in their current locations. Yields would be expected to increase in some locations but also reduce in others. Analysis in Section 3 suggested gradual climate change may cause a fall in the potential production of forests in England of up to around 40% by the 2080s (assuming a high emissions scenario), and potentially up to 7% in Wales. In Scotland, potential production is projected to increase by the 2050s by some 20% but then fall by around 17% by the 2080s. These results are presented for the high emissions scenario only; there is uncertainty around these estimates given the long time-frames involved (see Annex 2).

There is an opportunity for planting the most resilient species today for future climate conditions. However felling rates are very low, with only 0.8% of the current area of broadleaf and conifers restocked in 2011 across the UK (this figure is lower for England). The ability to change the current stock of species is therefore limited. Opportunities to plant species likely to be resilient to climate change in the expansion of woodland have also been evaluated in this analysis.

Scenario 1 explores potential production if all restocking, or new planting between 2011-2050 uses the species which is projected to achieve the highest yield in the 2050s. Similarly, the species with the highest yield in the 2080s is planted between 2050 and 2080. Due to the extent of current outbreaks of

Dothistroma needle blight on pine species[46] and *Phytophthora ramorum* on larch, no restocking of these species has been used in this scenario. Results are in **Figure 13**.

Figure 13. Scenario 1: What if forest owners/managers restock and planted with the highest yield class species (given projected climate change) in the 2050s and 2080s?



Source: Based on ESC modelled yield classes and restocking rates for 2011 (FC, 2012) This analysis assumes that forest cover increases each year up to half of the aspirational levels set by England and the DAs, much of which is set to be achieved by the 2060s.

Figure 13 illustrates that if all forest owners selected species to plant from 2012 onwards to maximise yields in the 2050s (in this illustrative scenario it is assumed they would plant the species with the highest yield class in the 2050s for their region of the UK), the impact on potential production for the UK as a whole by the 2050s and 2080s is expected to positive. However, even with the best performing species, not enough restocking is expected to take place in England to mitigate fully the potential impact of climate change by the 2080s.

The limitation of this scenario is that it could discourage species diversification; focusing only on the high yield species could in theory create greater exposure to pests and pathogens, for example. The analysis also only considers a relatively narrow range of species that have been planted widely in the past. A future analysis could consider a wider range of species, including many of those

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[46] The suitability of alternative pine species not assessed in this report, for example *Pinus peuce*, is under investigation.

identified as being worthy of consideration in the Read Report (Read *et al.,* 2009a) and incorporated into ESC version 3.

The effectiveness of the adaptation action tested in Scenario 1 may be enhanced by either:

- Increasing woodland cover, providing greater opportunity to plant more climate resilient species, or
- Encouraging more active management of woodland, which may result in higher levels of restocking.

To illustrate the potential additional impact of such actions, Scenario 1 has been extended to incorporate a range of actions which represent current aspirations for levels of woodland cover and woodland management.

The two scenario extensions are:

- **Scenario 1a:** It has firstly been extended to represent a potential impact of increasing the area of woodland under active management. To illustrate this, increasing levels of woodland actively managed from 58%[47] to the aspirational level of 80%[48] is assumed to proportionately increase the rate of restocking undertaken between 2011 and 2050. All restocking uses the best performing species (with the highest yield classes under the high climate emissions scenario in the 2050s).
- **Scenario 1b:** It has also been extended to represent different increases in woodland cover. The range used in this analysis starts at a low-level, assuming annual increases in forest cover remaining at the 2011 area increase; and a high level of forest cover increase, which is the linear rate of increase required from today to reach the England and DA aspirational levels of forest cover to 2050, as illustrated in the scale of the challenge, **Figure 3**.

Table 8 illustrates the increase in potential production which could be achieved by the adaptation action undertaken in Scenario 1 (diversification by planting high yield class species), if actions were also taken to increase active woodland management (Scenario 1a) and woodland cover (Scenario 1b).

[47] This is the current proportion of woodland with a management plan or equivalent (Gillam, 2012)

[48] This aspiration relates to sustainably managed woodland (IFP, 2012)

Table 8. Illustrative increases in the potential production achieved by the 2050s under Scenario 1.

	Current levels of woodland under a management plan or equivalent (58%) and current re-stocking rate	Aspirational levels of woodland management are achieved (80%) and reflected in levels of restocking
The current level of new forest cover growth continues	Base case	Increase of 2%
New forest cover is increased to reach half the aspirations of England and the DAs	Increase of 7%	Increase of 9%
New forest cover is increased meet the aspirations of England and the DAs	Increase of 16%	Increase of 17%

Source: Based on ESC modelled yield class and restocking rates for 2011 (FC, 2012). Applying aspirations for woodland cover in England from 10% to 13% by 2060 (Natural Environment White Paper, 2011); increase forest cover in Scotland by 10,000 hectares per year from 2012-2022 (Scottish Forestry Strategy, 2006); create 100 000 hectares of new woodland in Wales between 2010 and 2030 (Ministerial announcement, 2010); and increasing forest cover in Northern Ireland from 6% to 12% from 2006 to 2056 (Northern Ireland Forestry: a strategy for sustainability and growth, 2006), and aspirations for sustainable woodland management to 80% expressed by the Independent Panel on Forestry (IPF, 2012).

The base case is potential production if all new planting uses species with the highest yield class in the 2050s, where there is no change in the 2011 level of woodland management and only the 2011 increase in woodland cover is applied each year

Under scenario 1a (increasing active forest management which increases re-stocking rates in proportion), the results illustrate that:

- Without active management, adaptation action cannot be implemented. Therefore, managing forests to facilitate diversification can increase potential production in 2050, relative to a case of no additional adaptation. Potential production is estimated to be 5-7% higher. When active management is extended further (illustrated through increased re-stocking rates) then potential production is estimated to be 7-9% higher than without adaptation action.

- This relatively lower level of increment to potential production when active management is increased may be due to the generally low re-stocking rates so even if re-stocking rates increase by 38%, it remains very low overall.

For scenario 1b (increasing forest cover), the results show:

- Although increasing forest cover will increase the area of forest exposed to climate change, where additional planting is with the high-yield species, increased forest cover would be expected to deliver increased potential production.
- Keeping re-stocking rates the same as today (but re-stocking with high-yield species), relative to the case in which the current rate of increase in forest-cover is assumed, increasing forest cover could add 7% - 16% yield production

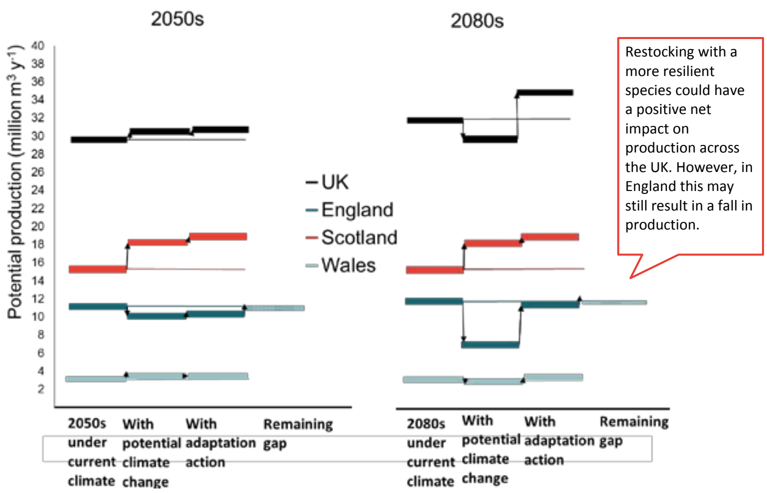
Scenario 2: What if research was undertaken and climate resilient provenances/populations/genotypes were identified and used to restock forests?

Research and breeding programmes could be undertaken to identify provenances of native and commonly planted species that maintain the current yield of those species under future climate conditions. The impacts of this are explored in this scenario.

This scenario assumes a research period of 20 years; climate-resilient populations/provenances are identified at the end of that research and the species restocked each year will be in proportion to the current distribution of the individual species. If yield classes of current species are projected to increase under future climate conditions, these increases are assumed to be maintained. Where the species yield declines in a particular location under projected climate conditions, this scenario assumes that after 20 years, owners will be able to restock and plant new forest with species or provenances for which yield class is equivalent to the base case yield class (assessed by the ESC model between 1960-1990), in the absence of climate change.

Results are shown in **Figure 14**.

Figure 14. Scenario 2: What if research was undertaken and climate resilient provenances/populations/genotypes were identified after 20 years and used to restock forests?



Source: ECR analysis using ESC yield projection and restocking rates for 2011 (FC, 2012). This analysis assumes that forest cover increases each year up to half of the aspirational levels set by England and the DAs, much of which is set to be achieved by the 2060s.

As with Scenario 1 **Figure 14** shows opportunities from yield class increases could increase overall potential production in the UK. In England, where the productivity of many species is projected to decline under future climate conditions (high emissions scenario), more resilient provenances would lessen the decrease in potential production. In this scenario, the long research period combined with low restocking levels implies a potential case for further action by the 2050s in England, which lessens to the 2080s when more restocking of the climate resilient species has had a greater effect. Such issues in England could be lessened by, for example, shortening the long research periods through the immediate planting of operational scale trials and implementation of adaptive management.

The scenario presented in **Figure 14** is based on a medium increase in forest cover (meeting 50% of the aspirational woodland expansion). If forest cover aspirations were fully met, this implies greater opportunity to plant climate-resilient provenances.

It should also be noted that a worst-case scenario is that no resilient populations/provenances/genotypes are identified through research. However, experts in the sector are more confident that there could be provenances from Europe, for example, which may be better adapted to the future climate of the UK.

6.2.5 Diversifying species choice to mitigate uncertainties and exposure to pest and pathogens

Scenario 3: What if owners were to diversify species and restock with less of the most prevalent species in a region?

This scenario explores enhancing climate resilience of forests over time by increasing the use of species less frequently planted, therefore diversifying the species mix at a stand, woodland or landscape scale[49]. Scenarios 3 and 4 illustrate the effectiveness of diversifying species in two extreme scenarios of climate change impacts.

Many of the impacts of climate change are subject to uncertainty (see Annex 2 for further detail of climate change uncertainty). Diversifying species could reduce exposure to those, as yet unknown, pests and pathogens which affect specific species. Experimental evidence suggests that pest abundance or damage could be reduced in mixed-species rather than monoculture stands (Wainhouse, 2005)[50]. Mixtures at different scales can therefore build resilience against pests and pathogens and be part of the strategy for adaptive management.

This scenario illustrates, as an example, the green spruce aphid as presented in the CCRA (Moffat *et al.,* 2012). This report focuses on the impact on the potential increase in the proportion of forest affected. The degree of lost potential production due to a serious outbreak of the insect pest will, however, be important in determining the extent of adaptation actions likely to be required. Evidence suggests that the green spruce aphid may have a comparatively lower impact on tree growth than other pests and pathogens[51]. Other pests and pathogens may have a much more acute impact and may spread in a much shorter time-frame, allowing for less adaptation. Examples of such pathogens currently affecting forestry in the UK include *Dothistroma septosporum* (the fungus causing Red Band Needle Blight on pine species) and *Phytophthora ramorum* on larch. In such cases, the ability to diversify at current felling (and restocking or new planting) rates would be reduced.

In **Figure 15** the first bar represents the proportion of spruce forest which could potentially be affected by the aphid in the 2050s with unchanged climatic conditions. The second bar represents the additional area of spruce forest affected under a high emissions scenarios in the 2050s. The third bar indicates

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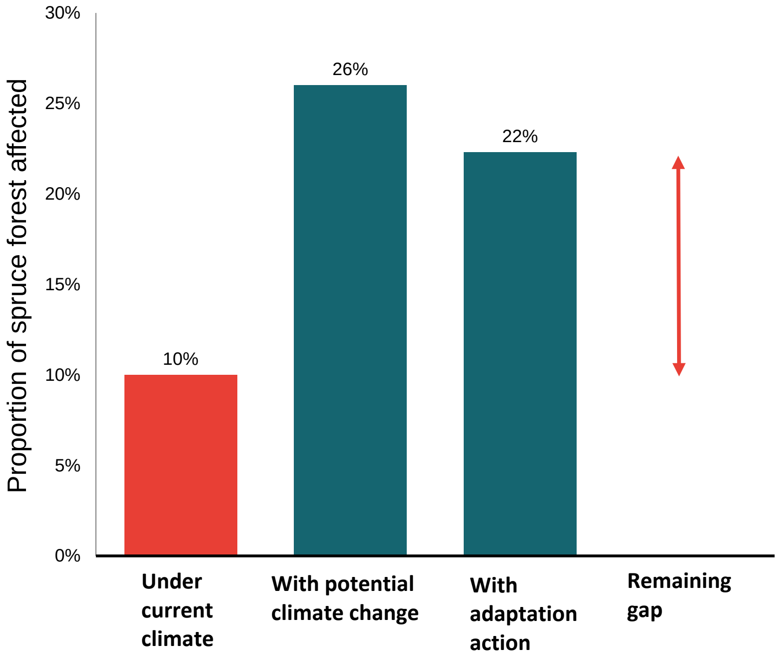
49http://www.forestry.gov.uk/forestry/infd-8bag9s

50 Wainhouse, (2005) finds: "Factors that may influence pest abundance in monocultures include concentration of potential food resources, making them easier to find and exploit, and reduction in effectiveness of natural enemies. Natural enemies for example, may be more abundant and effective in diverse and complex plant cultural systems because they can utilise a greater range of prey."

51 Where the green spruce aphid attacks a timber crop throughout its growth period, it can result in a reduction of 2-4% of gross income (on a discounted basis), (Moffat *et al.,* 2012).

that species diversification would be expected to mitigate some of the potential effects of the aphid pest by reducing the area of spruce forest. This is however, constrained by the low level of re-stocking. Also, replacing the Sitka spruce species exposed to the aphid with the next best performing (i.e. next best yield class) species would be at the cost of lost annual potential production. Such losses in potential production would need to be balanced against the benefit of greater resilience.

Figure 15. Scenario 3: What if owners were to diversify species and restock with less of the most prevalent species in a region?



Source: ECR analysis using Moffat *et al.*, (2012) green spruce aphid impacts.

Results are shown for the 2050 drawing on projected yield classes under a high emissions scenario to the 2050s with the growth in forest cover at half the levels aspired to by counties in the UK by 2050.

Scenario 4: what if the impacts of a severe pathogen outbreak, which would otherwise cause the sanitary felling of a prevalent species (illustratively shown to be Sitka Spruce), were reduced (in part) through re-stocking with a more diverse range of species?

The impacts of disease in forests can be substantial. Examples of current tree diseases in the UK which may be spreading at a more rapid pace than the green spruce aphid include *Dothistroma* Needle Blight (red band needle blight) on some pine species and the *Phytophthora* outbreak on larch.

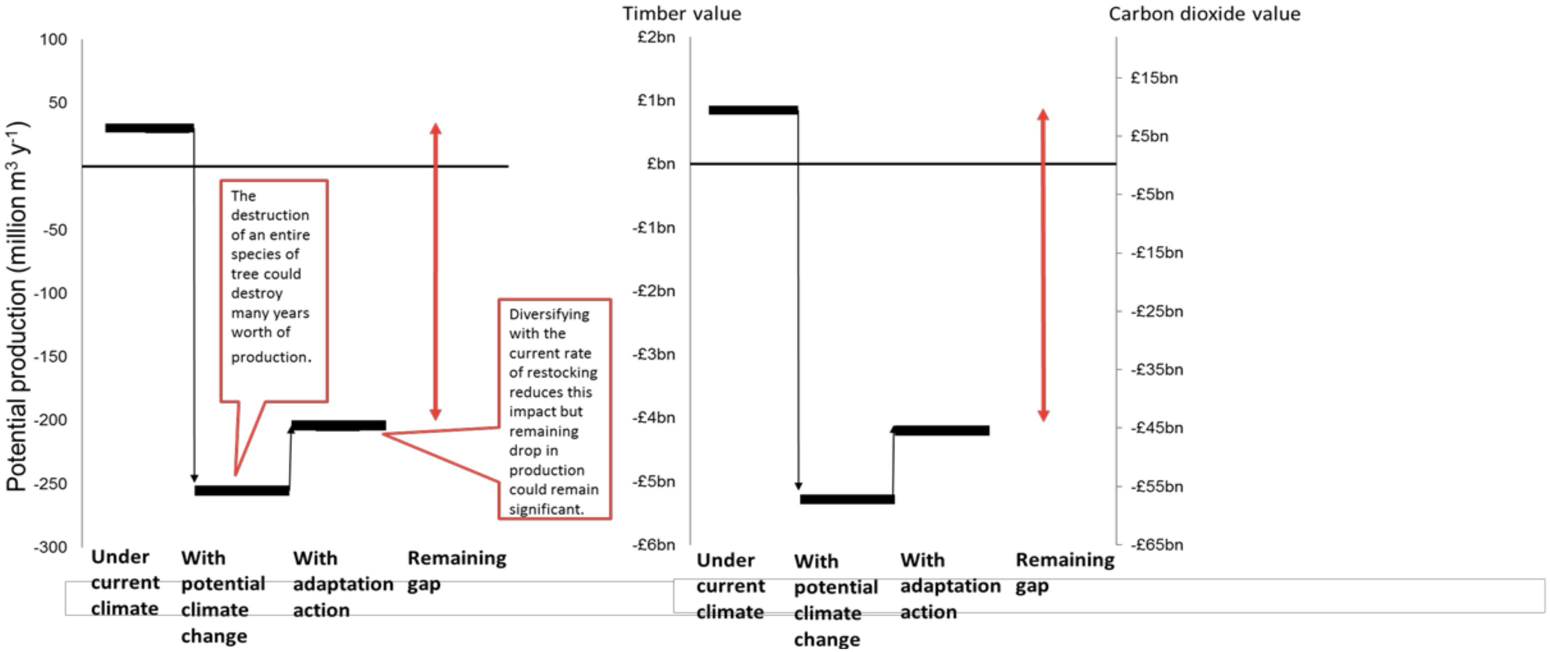
In this scenario, the infected trees are felled, and are assumed to have zero value. In practice, the felled timber may still be valuable for uses such as bioenergy production, so the illustrated lost value should be considered the upper bound; the lower bound is unknown because it would depend on how much of the timber was used for bioenergy and its price. If half of planned planting of the prevalent species between 2011 and 2050 were replaced with other species, this would reduce the impacts of climate change on potential production.

In **Figure 16**, the potential impacts are shown as both the impacts on potential production (left hand side), and on the carbon and timber values (right hand side). The impact on growth shows that moving from the first bar (current climate) to the second (future scenario assuming climate changed disease outbreak) implies a substantial loss of production. Adaptation action, as illustrated here, could reduce this loss, perhaps by around 50 million cubic metres. However, it would not be enough compared to the loss of 300 million cubic metres as a result of the disease outbreak. It should also be noted that the adaptation measure (i.e. species diversification) is assumed to reduce the severity/incidence of the disease in the remaining crop.

If this scenario explored a similar impact on a hardwood species (for example if a native species of oak was affected to the same severity as larch is currently affected by *Phytophthora ramorum*), then it would be expected that the case for action would be larger still due to the longer rotation of most hardwoods.

Each of the actions in these scenarios is more likely to be implemented if forests are brought under management.

Figure 16. Scenario 4 what if a disease outbreak that required sanitary felling was addressed by diversifying planting of dominant species? Results are shown for the high emissions scenario and assumes that half the increase in woodland cover aspired to by countries in the UK is achieved.



Source: ESC analysis using Sitka spruce stock levels from the National Forest Inventory Report (Forestry Commission, 2012a)

Timber value uses timber prices assessed by the Forestry Commission, and assumes that once felled there is no market value. This should be viewed as an extreme estimation of the impact as it is likely there will be some uses, and thereby market value for the timber.

This scenario makes the assumption that when felled all carbon stored will be emitted to the atmosphere. The value of the carbon loss should be viewed as the upper bound as it is likely that a proportion of the timber would be used in durable wood products and not immediately lost to the atmosphere.

Case for intervention

6.3 Recommendations for intervention

The case for intervention by government or other bodies may exist where:

- There are **significant barriers or constraints** to taking effective adaptation action. This may be because markets lack the required information to allow appropriate signals to be sent to parties to take appropriate action.

- Where **the UK may become 'locked in'** to a path that could lead to maladaptation or removes **required flexibility effectively to manage uncertainty.**

- Where actions could **otherwise be taken too late** relative to what would be a value for money approach to address a particular climate threat.

- **Some parties may be affected more significantly than others, but lack the adaptive capacity** to be able to prepare for climate change.

This leads us to some conclusions about the case for intervention.

6.3.1 Identifying the case for action

Barriers were identified in Section 5. These are summarised below along with the recommended interventions to address them.

Market failures

Externalities can be identified in several forms:

- **Notable proportions of forest are not subject to active management**. In such forests there is little, if any, ability to ensure they are adapted to future climate change. Only 57% (48% in England) of forest and woodland has a management plan or equivalent (Gillam, 2011).

- **Where forests are subject to active management, the incentives for forest managers to protect ecosystem services may be limited by the lack of private return from doing so. Returns may also not be realised within a feasible time-frame owing to the low activity levels caused by the very long rotation periods of typically 40 to 50 years** (and up to hundreds of years for some hardwoods) and the annual restocking rate of only 0.2% in England (FCE, 2012). The benefits of species or provenance selection actions may therefore take many decades to be realised.

Information failures are evident from a range of perspectives:

- **Forest managers are often not aware of climate-resilient provenances and species to meet long-term timber production needs and ecosystem services delivery**. Availability of climate resilient species and provenances means projected climate change is not consistently reflected in new planting decisions. In addition, there are few climate-resilient tree species presently available from UK nurseries that could outperform existing species.

- **Little evidence is available on the costs and benefits of adaptation actions** and the conditions under which they are likely to be effective.

Policy failures

There are currently **no formal markets**[52] **to allow the economic benefits of enhancing or protecting biodiversity**, **sequestering carbon or other ecosystems services, to be realised** by forest owners. Policy addresses this, in part, through grants. However, the current level of grants available is not likely to be sufficient to increase forest land-cover where land competes with more economically productive uses, such as agriculture.

Behavioural constraint

'Short-sightedness': as noted above, at present commercial managers are considering new species but most are not planting with a view to climate change.

Governance barriers

Co-ordination barriers: Forest ownership and boundaries straddle the catchment and therefore there are difficulties in co-ordinating actions.

To address these barriers, recommended interventions are the following.

Recommended intervention

Enhance adaptive capacity by exploring practical and cost-effective ways to **reduce the amount of under-managed woodland.** This should be complemented through the delivery of tailored, practical knowledge and advice to forest managers about appropriate management techniques; and addressing both behavioural barriers and market failures which mean managers have little incentive better to manage forests (e.g. by creating market mechanisms or grants).

[52] However, less formal payments for carbon sequestration in woodland creation projects can be realised through certification to the Woodland Carbon Code.

Greater pro-active management of forests is expected to increase resilience in relation to drought, pests and pathogens, forest fires as well as other gradual climatic changes. This is because only in managed forests could many of the adaptation actions be implemented (i.e. re-stocking with more resilient species and increasing diversification to reduce the risk of pests and pathogens.)

At the stand level, use of smaller coupes for clear-felling and introducing resilient provenances/species could be implemented. Alternatively, effective use of continuous cover forestry to create diverse forest structures could also enhance preparedness of forests to climate change. At the forest-level, active management would better facilitate mitigation of the adverse impacts of fires, pests and pathogens, or make the most of potential opportunities (through expanding forest cover with resilient species, for example).

Recommended intervention

Encourage and facilitate through research and demonstration the planting of climate-resilient provenances and species to meet long-term timber production needs and ecosystem services delivery. Ensure timely and tailored information is available to forest owners and managers on the most climate-resilience provenances and species. Information for forest managers must be practical, easily accessible and targeted – this is essential to build adaptive capacity.

Much can be learned from overseas where climate conditions are similar today to those projected for the UK in the future. However, research would be required to understand their likely performance under current UK conditions. At the same time, the capacity of the forestry industry to provide and subsequently process alternative species once they are identified and grown can be increased. This involves raising awareness of implications for investment in the timber-processing sectors and understanding the future market for timber from these alternative species.

Recommended intervention

Address remaining market failures to support the protection of ecosystem services. Market mechanisms should be explored which facilitate the protection and enhanced delivery of ecosystem services from woodland. The Woodland Carbon Code, the development of the Environment Bank and biodiversity offsets are recent examples.

Recommended intervention

Undertake research and analysis to identify appropriate interventions to facilitate the co-ordination of forest adaptation action between owners at forest/catchment-scale. Implement effective interventions. At the same time, efforts to encourage woodland creation to deliver cross-sectoral benefits (including enhanced resilience to climate change) need to promoted.

Co-ordination of activity between forest owners could facilitate a number of adaptation actions. For example, it could increase connectivity between forests (e.g. to facilitate gene flow). Co-ordination could also deliver wider benefits for the protection of ecosystem services beyond those available at the forest level.

Recommended intervention

Undertake case study analysis of adaptation actions through robust analysis of the costs and benefits of a range of actions and the conditions under which they are likely to be effective. Adaptive capacity should be built by exploring practical steps to learn from overseas and UK practices to increase resilience – monitoring, reviewing and sharing of lessons should be carried out.

Long term and/or continuous monitoring and evaluation of the effect of activities at stand, forest and landscape scale would be expected to increase the ability to optimise the value (market and non-market) of forests in the long-term.

Annex 1 - Stakeholders

The ECR team is very grateful to the following for their valuable input to this work:

Managers of public forest

Forestry Commission England - Mark Broadmeadow, Rob Gazzard and Mike Render, John Tewson, Pat Snowdon

Forestry Commission Scotland – Jo Ellis

Forestry Commission Wales - Helen Cariss

Forestry Commission Climate Change Strategy Group – Tim Rollinson

Forest Research: Tom Nisbet, Gregory Valatin, Andrew Moffat, James Morison and Duncan Ray

Forestry sector organisations

Confor – Caroline Harrison

UPM Tillhill – George McRobbie

Institute of Chartered Foresters – Julian Evans

Organisations with biodiversity objectives

Natural England – Mike Morecroft, Keith Kirby

Other stakeholders

Secretariat to the Independent Panel on Forestry - Emma Powell

EWGS Applicants Focus Group – Andrew Smith

Sylva Foundation – Gabriel Hemery, Alastair Yeomans

Future Trees Trust - Peter Savill

Rural Development Initiative- Martin Glynn

John Clegg Ltd - Guy Watt

Government Departments

Defra - Bradley Bates

Department of the Environment (NI) - Valerie Hamilton, Stuart Morwood, and Michael McCallion

Energy and Climate Change Division (Welsh Government) - Nicola Britton and Emma Edworthy

Climate Change Legislation Team, The Scottish Government - Jody Fleck

Case for intervention

Annex 2 – Uncertainty of climate change projections[53]

This annex begins with an explanation on the background on uncertainties associated with climate projections. It is followed by a paragraph that explains the UKCP09 methodology and how uncertainties are accounted for. The next paragraph explains how to interpret probabilities in UKCP09 output for given emissions scenarios and the Annex ends with a discussion on the limitations of UKCP09.

Background on Uncertainties in Climate Projections

There are three major sources of uncertainties in estimating future climate change:

- Natural Climate Variability
- Incomplete understanding of Earth System process and the inability to model the climate perfectly
- Uncertainty in future greenhouse gas emissions

The major sources are discussed individually below.

Natural Climate Variability

Natural variability has two principle causes. One arises from natural internal variability which is caused by the chaotic nature of the climate system. Ranging from individual storms which affect weather, to large scale variability due to interactions between the ocean and the atmosphere (such as El Nino). Climate can also vary due to natural external factors. The main causes are changes in solar radiation and in the amount of aerosols released (small particles) from volcanoes.

Representation of Earth's System in Climate Models

The second main source of uncertainty arises due to modelling of the future climate. The only way we can calculate how the climate will change due to human activity is through the use of mathematical models of the earth's climate system. These models are known as Global Climate Models (GCMs). They describe the behaviour of different climate components and interactions between them. The components include the atmosphere, the oceans, the land and the cryosphere. Each interact to produce many types of feedbacks, both positive and negative. The net effect will determine how climate evolves in response to changes in greenhouse gasses.

[53] This chapter is largely based on Murphy et al., 2009 and UKCP09, © UK Climate Projections, 2009.

Uncertainty in models is caused by an incomplete knowledge of the climate system and the inability to model it perfectly. Representations of physical processes within the climate system are based on a mixture of theory, observations and representation. Representations may be limited by physical knowledge, but also by computing power and lead to errors, which inevitably cause uncertainty. All modelling groups seek to represent climate processes in the best possible way in their models. This is based on subjective judgement, which causes different strengths of feedbacks in different models. This means that different models give different results, although they all use plausible representations of climate processes.

Future Greenhouse Gas Emissions and SRES

The final source of uncertainty arises due to future emission scenarios of greenhouse gasses and aerosol. This will depend on many socioeconomic factors such as changes in population, GDP, energy use and energy mix. The Intergovernmental Panel on Climate Change (IPCC) published a Special Report on Emission Scenarios (SRES) (Nakićenović and Swart, 2000), in which climate-relevant emissions were calculated based on a number of storylines. Each of these storylines describes a possible way of how the world might develop. Differences between them arise due to the different assumptions about future socioeconomic changes. They assume no political action to reduce emissions in order to mitigate climate change.

UKCP09 projections

The UK Climate Projections (UKCP09) provides projections of climate change for the UK. These projections cover changes in a number of atmospheric variables, using different temporal and spatial averaging. They are given for several future time periods under three future emission scenarios.

Projections of the climate variables in UKCP09 methodology are made using multiple climate models. The output of the climate models is used to estimate probabilities, rather than giving single values of possible changes. Probabilities are introduced to treat uncertainties associated with climate projections.

Uncertainties mentioned above are accounted for when doing climate projections. Uncertainties are treated by generating projections of change as estimated probabilities of different outcomes for given emission scenarios. This means that probabilities are attached to different climate change outcomes, which provides information on the estimated relative likelihood of different future results.

To do this, UKCP09 assumes that uncertainties manifest themselves in different climate projections from different climate models. Probability distributions of the future climate can then be generated by using projections from a large number of models or variants from a single model.

Case for intervention

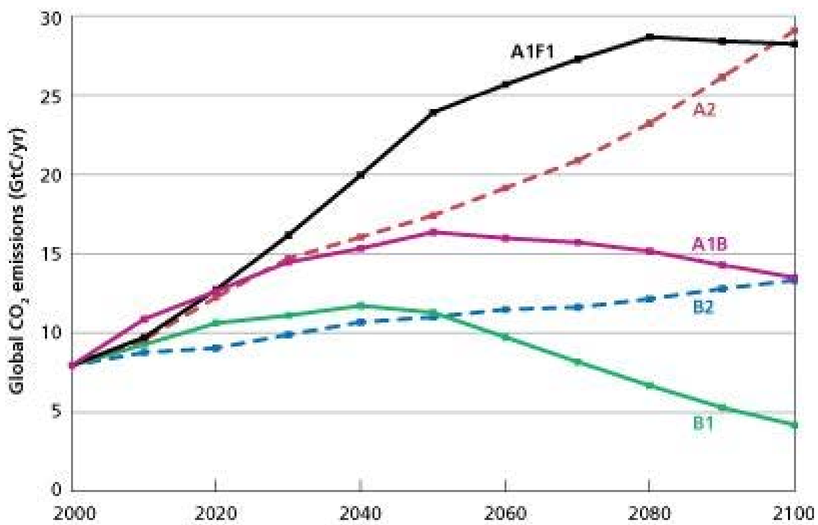
UKCP09 use a combination of projections from the following models:

- A very large number of variants of the Met Office Hadley Centre model
- 12 international models who participated in inter-comparison studies of the fourth IPCC report

Probabilities are based on a large number (ensembles) of climate model simulations, but adjusted according to how well different simulations fit historical climate observations. This is done in order to make them relevant to the real world. By presenting probabilities based on ensembles of climate models, UKCP09 takes into account both modelling uncertainty and uncertainty due to natural variability.

It does not however include uncertainty due to future emissions. Currently there is no accepted method of assigning relative likelihoods to alternative future emissions. UKCP09 therefore presents probabilistic projections of future climate change for 3 future emission scenarios. They are selected from three scenarios developed in SRES and referred to as Low, Medium and High emissions, which corresponds to A1FI, A1B and B1 scenarios in SRES. Figure 1 indicates these scenarios in terms of CO2 emissions with solid lines (black: High Emissions, purple: Medium Emissions, green: Low Emissions). Each scenario also includes emissions of other greenhouse gasses however. Although the three UKCP emission scenarios span the range of marker scenarios in SRES, there are additional scenarios, both higher and lower, that they do not encompass.

Figure 17. Global annual CO2 emissions (expressed as gigatonnes of carbon) under the three IPCC SRES scenarios



Source: Murphy et al., 2009

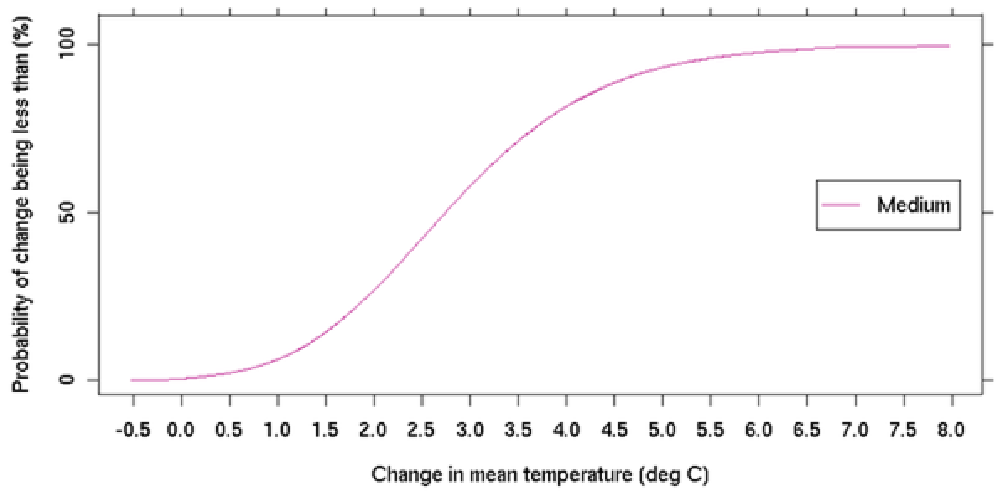
Note: Dotted are two SRES emission scenarios used in previous UK Climate Projections, but not in UKCP09.

Probability in Climate Projections

Probabilistic projections assign a probability to different possible climate change outcomes. Probability given in UKCP09 output is seen as the relative degree to which each possible climate outcome is supported by the evidence available. It takes into account the current understanding of climate science and observations.

Probability in UKCP09 does not indicate the absolute value of climate changing by some exact value. Instead it states the probability of climate change being less than or greater than a certain value using the Cumulative Distribution Function (CDF). This is defined as probability of climate change being less than a given amount. An example is given in **Figure 18**. The CDF (for the 2050s mean summer temperatures in the London area, with a medium emission scenario) shows that there is a 10% probability of temperature change being less than about 1 degree and 90% probability of temperature change being less than about 5 degrees.

Figure 18. Example of Cumulative Distribution Function for the 2050s mean summer temperatures in the London area, with a medium emission scenario (0© UKCP09).



The figure above does not say that the temperature rise will be less than 5 degrees in 90% of the future climates, because there will only be one climate. It rather indicates that UKCP09 is a 90% probability (based on data and chosen methodology) that the temperature rise will be less than 5 degrees.

Limitations

The procedure used in UKCP09 to convert ensembles of climate models into probabilistic estimates of future climate also includes some subjective choices and assumptions. This means that the probabilities themselves are uncertain, because they are dependent on the information used and how the methodology is formulated.

The system can furthermore not be verified on a large sample of past cases. Current models are however capable of simulating many aspects of global and regional climate with considerable skill. They do capture all major physical and biochemical systems that are known to influence our climate in the future

Annex 3 – ESC model and potential production projections

Potential production of UK forests

To illustrate the potential impact of climate change on forests, a measure of potential production has been used which combines the modelled impact on productivity with land cover. This is illustrative of annual tree growth and not the volume of timber which is harvested annually.

The impacts of climate change on tree growth are estimated on the basis of yield class which is defined as the maximum average rate of volume production (where average means 'since planting/regeneration'). These are taken from the Forest Research Ecological Site Classification (ESC) model (Pyatt, Ray & Fletcher, 2001). Predicted yield classes have been multiplied by estimates of the area of each species growing in England, Scotland, Wales and Northern Ireland in the 2050s and 2080s. This allows an estimate to be developed of projected UK forest potential production in the 2050s and 2080s in the absence of climate change.

ESC yield modelling

The ESC modelling tool was used in Moffat et al (2012) to assess the impact of climate change on tree suitability and yield. This report extrapolates that analysis from public forests to private forest area to provide an indicative estimate of the scale of the impact of climate change on UK-wide forest production.

Species have different growth rates depending on intrinsic characteristics and the soil and climate conditions of the area. The ESC assesses yields of 14 different species (conifer and broadleaf) in 16 different regions across the UK, based on the information on the public forest. The ESC has been developed over a number of years and links species information for individual stands from the Forestry Commission sub-compartment database to soil type based on 1:250,000 soil maps.

This yield class (YC) represents the maximum mean annual growth rate of a tree since planting or regeneration. Harvesting stands at or shortly after the time when the mean annual growth rate reaches its maximum should give the highest long-term productivity for a site. At any time stands will be at a range of periods in their growth cycle, so the estimated YC is not the actual that can be realised at that time, particularly if not managed optimally. The age structure and management effectiveness of the forest cannot be projected with any accuracy in the 2050s and 2080s. The average growth of all forests could be two thirds lower than the best yield.

The ESC tool estimates YC of each species over 1961-90, linking climate and edaphic (soil) variables to known species performance. This is used to estimate potential yield class of tree species. Conditions measured include:

- Temperature (annual accumulated temperature)
- Summer moisture deficit
- Exposure (windiness based on the DAMS wind hazard classification system)
- Continentality (using the Conrad continentality index)
- Soil nutrient regime
- Soil moisture regime

The ESC model estimates YC under climate conditions in 1961-90 and under UKCIP02 temperature and moisture climate scenarios for the 2050s and 2080s. Only data on the high emissions scenarios was available for use in this report.

Extension to projection of potential production

To estimate the scale of potential forest production for the UK, the estimated YC from the ESC under high emission scenario conditions have been applied to estimates of total area of each species across the different countries. This presents an indicative estimate of potential production based on yield class information; a more detailed approach using predicted growth would require a complex analysis of the age of forest stands in the 2050s and 2080s - younger trees will be growing faster than older trees and historic planting levels will determine the current age distribution of trees.

Current total area for each species has been estimated from the following sources:

- Public forest area information is from the public forest estate. Area data is recorded on a finer scale than the National Forest Inventory (2011 with 2012 updates).
- Private conifer forest area is estimated using the latest National Forest Inventory, published in 2012 (Forestry Commission, 2011f). This provides area by species in England, Scotland, and Wales.
- Private broadleaf forest area is estimated from last full inventory of British forests undertaken by Forest Research between 1995-99 (National Inventory of Woodland and Trees). This provides area by species in England, Scotland, and Wales. Total area of broadleaves in 2011 has been published in Forest Statistics (2011). The relative proportion of the different species in the inventory has been applied to

the total 2011 area to identify total forest by species. How the distribution of species will have changed from 1990 to 2011 is unknown, and will be published in the updated National Forest Inventory later in 2012.

- Forest in Northern Ireland; total area of conifer and broadleaf forest in 2011 has been identified in Forest Statistics (2011). This distribution of species within this DA was not recorded in in the National Inventory. Similarly how well each species will grow under climate conditions of Northern Ireland was not assessed by the ESC model. To provide an indicative scale of the impact of climate change on the total UK, the average yield impact on conifers and broadleaves across England, Scotland and Wales has been applied to the total area of forest in Northern Ireland. The impact of climate change on forests in Northern Ireland has not been assessed separately and is only used to indicate scale.

Estimates of potential forest production in the 2050s and 2080s will depend on the yield class in the future, the amount of forest cover in the future, and the distribution of different species within the total forest area. To provide an indicative estimate of the scale of potential production, the current relative amounts of each species are assumed constant and the increase of forest cover from 2011 to 2050 and 2080 has been explored under three scenarios:

- Low forest cover growth – estimated using new conifer and broadleaf hectares planted in 2011 (2011 Forestry Statistics) multiplied by each year up to 2050 and again to 2080.
- Mid-range forest cover growth – estimates using aspirations for future forest cover given in **Table 9**. These aspirations are largely seen by the industry as ambitious, so the mid-range forecast assumes that only half the aspirational levels are met in the timeframe set and in the following years only new cover identified in 2011 (as in the low scenario) is planted each year.
- High forest cover growth – assumes that the forest cover aspirations are fully met.

Table 9. Devolved Administration aspirations for increasing forest cover

Country	Forest cover aspiration	Expressed in:
England	Increase woodland cover from 10% to 13% by 2060	Natural Environment White Paper (2011)
Scotland	Increase forest area by 10,000 ha a year between 2012-2022	Scottish Forestry Strategy (2006)
Wales	Create 100 000 hectares of new woodland between 2010 and 2030	Ministerial announcement (2010)
Northern Ireland	Double the area of forest from 6% to 12% from 2006 to 2056	Northern Ireland forestry: a strategy for sustainability and growth (2006)

Source: Forestry Commission (2011d)

Valuation of projections of potential production and other ecosystem services provided by forests

Ecosystem function is a loosely defined concept, but can be summarised as the way biological communities operate, interacting with each other and with the physical environment. It includes, for example nutrient and water cycling and energy transfers, as well as interactions between species, such as pollination and competition. The survival of species and habitats is dependent on these processes. Changes in climate can have a direct effect on forests by impacting on these processes, as well as through changing species compositions. For example, rates of decomposition and associated processes such as nitrogen mineralization are strongly influenced by soil temperature and water content. Changes in life cycles can disrupt food chains (e.g. Buse et al, 1999 and Perrins, 1991).

The key ecosystem services this assessment has considered are:

1. Provisioning – timber production
2. Regulating – carbon sequestration
3. Supporting and cultural – biodiversity, recreation, landscape and air pollution

There are a number of other ecosystem services which are not considered in this report.

Provisioning services

This report estimated annual tree growth as potential production, the value of which will only be realised when and if harvested. This report places a timber price value on that annual growth. This growth will apply to trees of all ages, many of which will not be at the end of their rotation period, so much of the growth will not be harvested for many years into the future (this could be hundreds of years in the case of hardwood). The estimate is termed potential production to show the estimated value if it has reached optimum harvest age. The value of potential forest production for timber provision has been assessed by multiplying yield growth by an estimate of the average softwood market price; Moffat et al (2012) identified this as £10.75[54] per m^3. Interviews with private forest managers suggested that the private market prices they are receiving for softwood is more commonly twice that of the sample assessed by the Forestry Commission, used in Moffat et al (2012), so a range of prices between £21.5 and £10.75 has been used. Due to a lack of available information on hardwood prices, a multiplier of two has been applied to this price to provide a price for hardwood, following the methodology used in Moffat et al (2012).

No increases in market prices for timber have been modelled. Typical forecasts for price increases tend to be associated with the price of oil and gas, however there are no additional assessments of future changes in demand and supply for UK timber. Through interviews with managers of forests for timber, the expectation is that prices would increase, however to what extent is unknown. Prices could vary with the use of biomass for electricity and heat in the future, and with any climate change effects on wood imports into the country (much of the imported timber is from Scandinavia and the Baltic states[55] which could be expected to experience a positive growth impact from climate change). Values have therefore been assumed flat (in real terms) so could be an underestimate of the potential value.

Regulating services

The value of forestry productivity in terms of its input into regulating services will focus, in this report, on its value for net carbon sequestration (the amount of carbon stored by the additional tree growth each year)[56].

The UK currently has a voluntary market which determines timber carbon values for offsetting carbon though forest planting. For this analysis, DECC non-traded carbon values were used (DECC, 2010) to estimate the value of carbon sequestered.

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54 At 2010 prices.

55 Forestry statistics 2012, - Trade, Figure 3.2 Country of origin of sawn softwood imports to the UK, 1962-2011
http://www.forestry.gov.uk/website/forstats2012.nsf/LUContents/45A4416DC7F75A9D8025735600334221

56The value of carbon stock in total UK woodland and to a greater extent sequestered into the soils through the tree, is estimated to be up to £28 billion in 2003 (NEA, 2011).

A national rather than project-level approach has been used to quantify the economic impact of climate change on timber production/growth rates on the carbon benefits derived from woodland. Changes in Yield Class of individual species at a regional level, as projected by the ESC, have been taken as representative of the impact on growth and therefore carbon sequestration. Since Yield Class is defined as the maximum mean annual volume increment over a forestry rotation (if assuming that the rotation ends at the time of maximum mean annual increment), this assumption only holds if (a) there is an even age distribution across the woodland resource (b) all woodlands are managed according to forest management tables. It needs to be understood that this method gives a mean impact at national/regional level and does not apply to individual stands. Changes in YC (m^3/ha/yr) were converted to dry matter production by applying published values for species specific wood densities.

Since YC only considers timber production, non-merchantable fractions (branch and root wood) were accounted for by applying biomass expansion factors. In addition to storing carbon in the stem grown, each year leaves, branches and tips will also grow which will additionally store carbon. The stem growth rates have been uplifted by the aggregate proportion of carbon in leaves, roots and branches to stems in British forests, using a higher proportion for broadleaves than for conifers (McKay et al., 2003). The proportion of carbon stored in the different parts of the tree will differ between species and over the life-cycle of the tree, the total amount of carbon may differ from this estimate. The additional amounts of carbon stored in the leaves, branches and tips compared to the stem, is estimated to be 80 per cent in conifers trees and 125 per cent in broadleaves (Morison et al, 2012).The amount of carbon in each m^3 grown each year is assessed as 50 per cent of the dried oven weight of m^3 of timber, using green volume carbon densities (Morison et al, 2012). The amount of carbon per m^3 of timber by species is presented in **Table 10**. To estimate carbon dioxide per m^3, the carbon volume is multiplied by 44/12. Carbon dioxide densities have been applied to the annual projected forest production to identify potential amounts of carbon sequestered in the 2050s under different climate conditions. The DECC non-traded value of carbon has been applied to estimate the undiscounted value of the carbon sequestered.

Table 10. Carbon dioxide density (tCO_2 per m^3) of common UK timber species

Species	Density based on oven dried weight and green volume
Sitka spruce	0.61
Norway spruce	0.61
Scots pine	0.77
Corsican pine	0.73
Douglas fir	0.75
Japanese larch	0.75
Hybrid larch	0.70
European larch	0.83
Ash	0.97
Birch	0.97
Oak	1.03

Source: Morison et al 2012

Table 11. DECC non-traded carbon values

	2011	2050	2080
Price per tCO_{2e} (at 2009 prices)	51 (in the range 28 to 83)	212 (in the range 106 to 318)	324 (in the range 113 – 535)

DECC *Valuing Greenhouse Gas Emissions for Evaluation and Appraisal, (2011)*

Although the approach taken to overestimates the amount of carbon stored in woodland, as removals through thinning and harvesting are not accounted for, this could be largely balanced by carbon storage in harvested wood products also not being accounting for. The carbon benefits arising from those products substituting directly for fossil fuels in the case of woodfuel used for energy production or indirectly through wood replacing more fossil-fuel intensive materials such as concrete and steel in construction, for example, is not considered. Indeed, when viewed in the long term, the total GHG emissions abatement associated with managed woodland generally exceeds that of woodland that is unmanaged where abatement is limited to carbon sequestration in forest biomass.

An alternative, project-level approach could be adopted using the 'carbon look-up tables' provided in support of the Woodland Carbon Code. These quantify carbon uptake in woodland over 5-year periods, allowing the dynamics of woodland growth to be accounted for. Although the approach would provide a more precise quantification of carbon storage in the woodland, the carbon abatement associated with the use of harvested wood products would again not be accounted for and total abatement would therefore be underestimated.

No value has been assessed for the carbon sequestered through trees into the soils, as understanding of how much may be sequestered in the future is uncertain. In many areas increased temperature and CO_2 concentrations will increase the rate of sequestration by trees, but this is likely to be balanced by increased rates of soil respiration in the short to medium term, depending on soil moisture and nutrient status.

Supporting and cultural services

The value of forests in terms of it cultural and supporting services have been taken from National Ecosystems Assessment (UKNEA, 2011) values for recreation, landscape, biodiversity and air pollution (other services may be provided but have not been measured). These values have been taken from willingness to pay assessments presented in Read et al (2009). It was estimated that the majority of this value will be received in England (Willis et al, 2003).

- Recreation £484 million (at 2010 prices)
- Landscape £185 million (at 2010 prices)
- Biodiversity £476 million (at 2010 prices)
- Air pollution £0.5 million (at 2010 prices)

These values represent the annual willingness to pay for the stock of forests (as opposed to just the annual stem growth)[57]. Annual forest production would contribute to maintaining these services.

How the importance of forests for cultural services would be likely to change in the 2050s and 2080s is currently uncertain. This report thereby does not attempt

[57] Landscape value only covers peri-urban areas because statistically significant results were not generated for other landscape types, it should be considered as potentially underestimating the landscape value of all UK forests.

to place a value on future potential production loss or gain under climate conditions in the 2050s and 2080s for supporting and cultural services provided/lost.

Climate change impact on production

Change in temperature and precipitation

The impact of changes in temperature and moisture in the 2050s and 2080s on tree growth has been estimated by the ESC model (as described above, limited to the high scenario and UKICP02 forecasts). Currently used forestry species are expected to perform better in more northern and western areas with climate change, so there may be a replacement of species in the south and east.

This analysis draws on the same evidence as the CCRA (Moffat et al, 2012): Forest Research's ESC model of temperature and soil implications for species yield. This is used to assess the impact of climate change under a high emissions scenario[58] on species potential yields in various different locations across the UK. Yields of 14 different species across 15 regions within England, Scotland and Wales are estimated (no data was assessed in Northern Ireland). Aggregated yield projections are shown in **Table 12** which shows increases in Scotland and decreasing yields in England.

Table 12. Projected impact of climate change on species suitability by country

Average annual forest potential yields in m^3 per ha (weighted by species, based on yield class									
	England			Scotland			Wales		
	Base	2050s	2080s	Base	2050s	2080s	Base	2050s	2080s
Conifer	13	11	8	11	13	14	14	16	14
Broadleaf	7	6	4	5	6	6	6	6	5

Source: Forestry Commission ESC model

UK overall projections differ from more localised projections at country level. The increases in potential yields are projected in areas such as Scotland. Sitka spruce, the predominant conifer species in Scotland and Wales is predicted to have some increase in yield in all regions within these countries. There are also

[58] This is the only scenario for which evidence was available, therefore results are to be considered towards the upper end of the potential magnitude of effects.

increased yields for some conifers in the north east of England (Corsican pine, Norway spruce and lodgepole pine), however much of the rest of England is projected to have decreases in the yields of all conifers (with the exception of Corsican pine). Yields of the hardwood species such as oak, beech, birch, sycamore and sweet chestnut are projected to decrease to less than half by the 2080s in the east and south of England.

Extreme events

The CCRA also assessed the impact of drought on forests under low, medium and high emission scenarios measured by the UKCP09.

Drought can cause tree mortality, often when in combination with other stresses such as pests and pathogens (Read et al 2009). The CCRA uses a response function which provides the percentage of yield loss under conditions of drought. It is measured by using the percentage of severely defoliated trees in regional tree crown condition survey data as an indication of drought impact, and relating this to the calculated previous maximum soil moisture deficit (Read et al 2009). The percentage defoliation indicator was then scaled to a percentage yield loss. **Table 13** contains the resulting projections for yield loss.

These reductions in yield over a base case reduction are applied to the projected forest cover (for each of the low, medium and high forest cover growth estimates) in 2050 and 2080. Average impacts across the water regions have been applied to the projected production by country.

This report does not assess any multiplied impact on tree growth through many periods of drought (e.g. a drought extending beyond one year), nor any increased impact of multiple droughts occurring within a year, and assumes each drought has the same impact. The ESC model, used to analyse long term climate change, assesses moisture levels but does not assess cases of severe drought.

Table 13. Projected (%) loss in yield due to drought

(central estimates of scenarios)		Low emission	Medium emission	High emission
Anglian	2050s	14	14	15
	2080s	15	16	18
Dee	2050s	14	14	15
	2080s	15	16	18
Humber	2050s	14	14	15
	2080s	15	16	18
North West England	2050s	14	14	15
	2080s	15	17	18
Northumbria	2050s	14	14	15
	2080s	15	17	18
Severn	2050s	14	14	15
	2080s	15	16	18
Solway	2050s	14	14	15
	2080s	15	17	18
South East England	2050s	13	14	15
	2080s	14	16	18
South West England	2050s	14	14	15
	2080s	15	16	18
Thames	2050s	13	14	15
	2080s	15	16	18
Western Wales	2050s	14	14	15
	2080s	15	17	18

Case for intervention

(central estimates of scenarios)		Low emission	Medium emission	High emission
Argyll	2050s	14	14	15
	2080s	15	16	18
Clyde	2050s	14	15	15
	2080s	15	17	19
Forth	2050s	14	15	15
	2080s	15	17	19
North East Scotland	2050s	14	14	15
	2080s	15	16	17
North Highland	2050s	14	14	15
	2080s	15	16	18
Orkney and Shetland	2050s	14	15	15
	2080s	15	17	18
Tay	2050s	14	14	15
	2080s	15	16	18
West Highland	2050s	14	15	15
	2080s	15	17	18
North Western Ireland	2050s	14	15	15
	2080s	15	17	19
Neagh Bann	2050s	14	15	15
	2080s	15	17	19
Tweed	2050s	15	15	15
	2080s	16	18	19

Source: CCRA (Moffat *et al*,2012)

Indirect Impacts

Climate change is likely to increase the activity and reduce the winter mortality of current insect pests and pathogens in the UK (Straw 1995). The exact impact of new pests and pathogens is not possible to determine. When a particular disease does occur in the UK, the damage can be large-scale and destroy the value of wide areas of woodland.

The CCRA assess the additional impacts of pests and pathogens caused by changing climatic conditions. It uses an example insect pest, the green spruce aphid and an example fungal pathogen, red band needle blight, to explore the potential risks to UK woodland. The analysis in the CCRA assesses the extent of woodland that could be affected by pathogens (for pine forest) and pests (for spruce forest) using a semi-quantitative, expert judgement approach, assessing the amount of forest affected under UKCP09 low, medium and high emissions scenarios.

The CCRA assesses the extent to which forest area for a given species could be impacted by red band needle blight in future periods of the 2020s, 2050s and 2080s, based on mean temperatures. It uses a base case that 9% of spruce forest in Great Britain will be affected by the green spruce aphid in the absence of climate change. By the 2050s under all climate conditions the CCRA estimates that a range of between 9-26% of spruce forest could be affected and in the 2080s this is for the low emissions scenario but could be between 9-52% under medium and high emissions scenarios.

The CCRA (2012) uses an estimation made by Williams et al (2010) that the impact of yield of an affected area of forest would be a 3% loss of yield. The CCRA did not identify a clear relationship between the impact on timber yield of pine when affected by red band needle blight. There are many other current pests and pathogens which are already causing severe damage to UK forests. Which pests and pathogens will be present in the 2050s and 2080s are unknown. As climate conditions become closer to those currently experienced in central and southern Europe or other warmer climates, pests which currently exist there could survive in the UK if introduced. The two assessed here should be considered an example of what could happen if a disease occurred.

The analysis follows the CCRA (2012) assessment of a current known pest, the green spruce aphid. The analysis is only indicative of the potential scale of impact of new pests and pathogens which may occur in the future.

Table 14. Estimated annual reduction in projected yield class caused by pests and pathogens due to climate changes – Impact of Green Spruce Aphid on spruces

	England	Scotland	Wales	Northern Ireland
Spruce as a % of total conifer area in region	37%	62%	69%	NA
Impact on yield of infection: loss of 3% of yield.				
By 2050s affected area increase to: (p50 central estimates)				
	Low emissions 9-10%			
	High emissions 13-26%			
By 2080s affected area increase to: (p50 central estimates)				
	Low emissions 9-13%			
	High emissions 26-52%			

Source: Underlying figures from CCRA: Moffat *et al*, 2012

What if scenarios using ESC modelling

What if species with the highest yields in the 2050s and 2080s are used for restocking (instead of the current species mix)?

Potential planting between 2011 and 2050 and the 2050s and 2080s have been estimated by assuming the restocking rates in 2011 (Forestry Statistics 2011), are continued each year. New planting using the high, medium and low scenarios for forest cover (noted above) are combined with restocking rates to provide an estimate for scale of planting which could be used to change the current species stock.

Table 15. Area restocked in 2011

Thousand hectares	England	Scotland	Wales	Northern Ireland
Conifer	1.86	8.64	1.52	0.74
Broadleaf	1.42	1.56	0.82	0.1

Source: Forestry Statistics 2011 (Table 1.8)

In Scenario I, the highest yield species are assumed to be planted in each location by applying relevant yields to the hectares of forest planted each year up to the 2050s and 2080s. This assumes that only one conifer and one broadleaf species per location is planted (this is likely to be an unrealistic scenario; however it shows the best adaptation action to maintain yield).

A simplifying assumption that the area for replanting between 2011 and the 2050s will be restocked with the species with the highest yield in the 2050s and area planted between the 2050s and 2080s will be planted with the species with the highest yield in the 2080s is applied. On the advice of experts it has been considered unlikely that planting of Corsican pine would take place, nor the lodgepole pine in Scotland or larch in Wales or the West of England, due to their present exposure to pests and pathogens. These have therefore not been considered as alternative species.

Table 16. Scenario I: Potential production (million m^3 per year) in 2050s under different assumptions for increased area of forest cover in the UK

	Low scenario Current restocking rate and no increase in forest area	Medium scenario Current restocking rate and half of the aspirations for increased forest cover met	High scenario Current restocking rate and full aspirations for increased forest cover met
Potential production under current climate	28	30	32
Potential production under high emissions climate scenario	29	30	33
Potential production if adaptation action is undertaken	31	33	36

Source: Based on ESC yield projections and Forest Inventory restocking rates 2011

Selection of the highest yield species may limit the diversity of species growing in the UK (or if more European species are appropriate this may increase the diversity).Where a particular species is vulnerable to a pest or disease in the future, decreasing diversity increases exposures to these risks.

Table 17. Scenario I: Potential production (million m^3 per year) in 2050s under the medium forest cover increase assumption by location

	England	Scotland	Wales
Potential production under current climate	11	14	3
Potential production under high emissions climate scenario	10	15	3
Potential production if adaptation action is undertaken	11	16	4

Source: Analysis using ESC yield projections and Forest Inventory restocking rates 2011

Table 18. Scenario I: Potential production (million m^3 per year) in 2080s under the mid-range forest cover increase assumption by location

	England	Scotland	Wales
Potential production under current climate	12	15	3
Potential production under high emissions climate scenario	7	18	3
Potential production if adaptation action is undertaken	10	20	3

Source: Analysis using ESC yield projections and Forest Inventory restocking rates 2011

For Scenario II it is assumed that sub-species or provenance of a species will be identified that are resilient to climate change and new planting would use these species. This scenario makes a simplifying assumption that for each species, a sub-species or provenance is identified which has the same yield in the 2050s and 2080s as it has in the ESC model (assessed between 1960 and 1990). It is possible that no such species will be found.

It then assumes the same restocking and new forest cover areas as in Scenario I. The scenario assumes all new planting is planted with the same species distribution as in 2011, and that either a new sub-species will be planted with the yields achieved before climate change, or in the cases where the yield is higher for some species under new climate conditions, the original species is planted to take advantage of this.

Table 19. Scenario II: Potential production (million m^3 per year) in 2050s under the mid-range forest cover increase assumption by location

	England	Scotland	Wales
Potential production under current climate	11	14	3
Potential production under high emissions climate scenario	10	15	3
Potential production if adaptation action is undertaken	11	17	3

Source: Analysis using ESC yield projections and Forest Inventory restocking rates 2011

Table 20. Scenario II: Potential production (million m^3 per year) in 2080s under the mid-range forest cover increase assumption by location

	England	Scotland	Wales
Potential production under current climate	12	15	3
Potential production under high emissions climate scenario	7	18	3
Potential production if adaptation action is undertaken	11	19	3

Source: ECR analysis using ESC yield projections and Forest Inventory restocking rates 2011

Scenario III and IV: What if owners were to diversify species and restock with less of the most prevalent species in a region?

Two scenarios are modelled which illustrate the impact of a pest (assumed in 2050 to illustratively be the green spruce aphid is affecting Sitka spruce).

- Scenario III assumes that the aphid is more active and affects more forest under new climate conditions than it would have in the base case, using the impact modelled in the CCRA.
- Scenario IV assumes that the aphid is very destructive and either destroys all Sitka spruce or that the remaining Sitka spruce is required to be felled to protect the spread of the pest. In this scenario the impact is illustrated by using total volume of Sitka in m^3 in 2011 identified in the National Forest Inventory (2012) and extending this to the illustrative year of 2050 by the rate of growth of new forest cover in the medium

growth scenario (above), to identify the stock of Sitka which will be lost to the aphid.

In both cases the adaptation action is that only half of the Sitka spruce planted between 2011-2050, based on the new planting estimates used for Scenario I and scenario II, is planted with Sitka spruce and that the other half is planted equally with the next three highest yield conifer species in each location. This tests the ability to minimise exposure to the aphid by the amount of planting (in particular restocking) available.

Changing to a lower yield species, however, also has a production cost. Although these what if scenarios do not consider the costs of adaptation measures, an indication of the yield cost has been included to highlight a barrier to adaptation.

Table 21. Scenario IV: Impact of a species destroying pathogen on spruce trees in the UK and the effect of diversifying half current levels of spruce restocking to another species

	Potential production (million m^3y^{-1})	Timber value (£ billion)	Carbon dioxide value (£ billion)
Potential production in 2050s under current climate (and no pathogen impact)	30	1	10
Potential production climate change resulting in species destroying spread of a pathogen	-255	-5	-57
Potential production if adaptation action is undertaken	-205	-4	-45

Source: Analysis, using Sitka spruce stock levels from the National Forest Inventory report 2012

Timber value uses timber prices assessed by the Forestry Commission, and assumes that once felled there is no market value. This should be viewed as an extreme estimation of the impact as it is likely there will be some uses, and thereby market value for the timber.

This scenario makes the assumption that when felled all carbon stored will be lost. The carbon value presented here should be viewed as an extreme estimation as further uses of the timber may maintain some of the carbon.

Limitations to these indicative estimates

The ESC model makes the best use of current information, but there are a number of limitations in the methodology, including but not limited to:

- Expanding the CCRA assessment from public forest to include private forest carries a number of unknowns such as differences in species, site types, soils, and management.

Case for intervention

- The version of the ESC model (version 1.7) used for this report does not contain enough data in Northern Ireland, so averages of the impacts within the other countries is applied to show UK wide scales of the challenge.
- The analysis only considers the direct impact of a number of climate change variables on yield. In practice, the impact of many climate change variables is likely to be complex.

Annex 4 - Policy

Role of government policy in adapting

- Aspirations for increasing the forest cover in England and the DAs are ambitious and far surpass the current rates of woodland creation.
- Policies are often aimed at protecting the contribution of forests to ecosystem services, for example, by providing the incentive to increase forest land cover, encouraging sustainable forest management and controlling felling through licensing. Market failures through the lack of private return from protecting biodiversity or other ecosystem services are recognised through the provision of grants to forest owners.
- In addition to domestic policy, there is a wide range of policy areas at EU level that impact forestry in the UK, including the EU's Common Agricultural Policy, Environmental Impact Assessment Directive, Habitats and Species Directive, Conservation of Wild Birds Directive, Renewable Energy Directive and Water Framework Directive.
- The UK Forestry Standard is the standard in the UK for sustainable woodland management, and one of the very few national forestry standards in the world that includes specific climate change guidelines that have adaptation requirements.
- Innovative new approaches, such as the voluntary Woodland Carbon Code, have the potential to substantially increase woodland creation by introducing new funds into forestry.
- Important barriers to woodland creation persist. In particular, the higher return and value of agricultural land relative to forests lowers the incentive to increase forest land-cover. Disparity between forestry and agricultural grant schemes imply greater returns from agricultural activities.

Introduction

This annex provides a brief overview of the policy landscape in relation to forests across England and the Devolved Administrations. It begins by looking at the EU context – from where many regulations derive – then focusing on UK specific issues.

The policy landscape

In England, the Department for Food and Rural Affairs (Defra) is responsible for forestry policy. Devolved responsibility was granted to Scotland and Wales in 1999, and to Northern Ireland in 1922 (CCRA: Moffat *et al*,2012).

The Independent Panel on Forestry was established in March 2011 by the Secretary of State for the Environment. The Panel's role is to advise Government on the future direction of forestry and woodland policy in England and on the role of the Forestry Commission in delivering policy. In formulating this advice, the Panel has been asked to consider how woodland cover can be increased, given competing pressures on land use and options for enhancing public benefits from all woodland including to enhance biodiversity, ecological resilience, public engagement and climate change mitigation and adaptation.

EU policy

Environmental Impact Assessment

When proposals for new planting, deforestation, forest road construction and quarries are deemed to have a significant effect on the environment, an Environmental Statement under the Environmental Impact Assessment (EIA) (Forestry) regulations [59] is required.

EIAs could therefore make more explicit the impacts of climate change on forests as they would need to be considered as part of the assessment of any proposed action which affected forests.

[59] This is Directive 85/337/EEC.

Invasive Non-Native Species Directive

Invasive non-native species are a major factor affecting biodiversity in the UK. Due to the potential threat posed by such species, the Invasive Non-Native Species Directive, Great Britain's subsequent Invasive Non-Native Species Framework Strategy and Scotland's Widlife and Natural Environment Act have been introduced. These could be considered barriers to adaptation action if they lower the incentive to plant non-native species and therefore limit species diversification as an adaptation measure. As could the EU's Directive on Alien Invasive species, which is due to be adopted in 2012 and is one of 6 key objectives under the EU's 2020 Biodiversity Strategy. Whilst this framework intends to enhance biodiversity by halting the spread of invasive alien species, it could discourage the introduction of new species.

Other EU policies

The Forestry Commission also has legal powers under the Plant Health Acts to prevent non-endemic pests and pathogens entering the country. The trade in 'reproductive material' (seed, plants etc.) is also controlled under Forest Reproductive Material regulations.

The EU's Common Agricultural Policy (CAP), Habitats and Species Directive, Conservation of Wild Birds Directive, Renewable Energy Directive and Water Framework Directive all impact forestry in the UK.

Under the EU Water Framework Directive, future water resource limitations could limit the potential for woodland creation and may also lead to the reversal of drainage schemes, reducing productivity and the resilience of existing woodland. Although soil protection can drive woodland creation on erosion-prone agricultural soils, measures to protect peat soil carbon stores could potentially reduce and fragment current woodland habitats. The Conservation of Wild Birds Directive may also limit woodland creation and provide a driver for woodland removal through open habitat restoration.

The EU Renewable Energy Directive could enhance funding for well-designed woodland creation but may lead to unsustainable woodland practices, reducing the resilience of the UK's woodland.

Inflexible interpretations of what tree species are classed as native, and therefore protected, tree species under the EU Habitats Directive could also limit adaptation where diversification would otherwise be a suitable adaptation action.

Any changes to CAP that further subsidise agricultural production or reduce axis II funding for forestry could reduce woodland creation further through increasing the incentive to use viable land for agricultural activity rather than forestry.

Potential impacts of policy on the ability to adapt

The **Natural Environment White Paper (2011)** outlines the Government's ambition for a "major increase in the area of woodland in England". The Read Report (Read et al, 2009) identifies woodland creation rates of 23,000 hectares per annum across the UK. In England this could mean increasing woodland creation rates from 2,300 hectares per year to 10,000 hectares per year over time, with woodland cover increasing from 9% to over 12% by 2060.

The Government has subsequently asked the Independent Panel on Forestry for advice on an appropriate level of ambition for woodland creation and more active management.

In England, the Forestry Commission issues 2,500 felling licences each year and has approximately 20,000 active grant schemes (FCE, 2012). Under current legislation, felling more than 5 cubic metres of growing trees per quarter is illegal in Great Britain and since 2010, in Northern Ireland, unless a license is obtained or the trees are below a specified size or deemed dangerous. The Forestry Act (1967) means that replanting after felling is usually required except where trees or woods are subject to designation (e.g. under Site of Special Scientific Interest or Tree Preservation Order), then consent from the relevant statutory authority is necessary for management. An unconditional felling licence may be issued by the Forestry Commission in such cases, which may also be subject to Environmental Impact Assessment (Forestry) regulations. If woodland is felled for development, it is subject to the requirements of the Town and Country Planning Act.

Despite these aspirations and commitments, annual planting rates having fallen since 2004/05 (Defra, 2011), presenting a challenge for Government[60].

Current UK Policy

The external benefits of forests – notably biodiversity, carbon sequestration, water and nutrient cycling, recreation and landscape value – are estimated to significantly exceed the private returns to owners, for example from the timber market. Missing markets for these 'public-good' services mean there is insufficient market incentive for woodland creation and government intervention is consequently justified. Current policies recognise this and largely aim to address these market failures.

Rural Development Programme

(i) The English Woodland Grant Scheme (EWGS)

[60] Although this was primarily due to a change in focus from 2005 on woodland management rather than planting new woodlands.

The EWGS looks to support the management of existing woodlands through the Woodland Regeneration Grant, Woodland Improvement Grant and Woodland Management Grant[61].

URS (2012) explored potential returns from available grant payments for planting broadleaves on non-severely damaged land under EGWS. Allowing for the cost of establishing a small farm woodland for broadleaves suggests a potential return of approximately £1,250-£4,400 per ha could be earned over 15 years. This excludes the selling of timber and any other private benefits (URS, 2012).

Opportunity costs of the use of land should however be considered. Where using land for forestry precludes agricultural use, grants may not provide adequate incentive.

According to Savills (2011), present land prices for Grade 3 arable land or poor grassland reach between £7,000-12,000 per ha (though this will be higher across parts of England). The overall return from planting forest is therefore likely to be lower than could be achieved from agriculture activity (where the latter is viable)[62].

For there to be a large increase in woodland in the UK, forestry would need to become more competitive with farmland, which is the main reserve of potential planting land in England (URS, 2012).

Missing markets for the external benefits of forest services are therefore a substantial barrier to the incentive for those services to be provided because they could affect relative returns and change the balance. This suggests a case for government intervention to address this market failure. In turn, this would also be expected to increase the incentive for adaptation action to ensure sustainable forestry.

(ii) Environmental Stewardship (ES)

ES is an agri-environment scheme that provides payment for farmers and land managers in England who manage their holdings so that they protect and enhance the environment and wildlife.

Under ES, Higher Level Stewardship (HLS) aims to establish small-scale woodlands through 'habitat creation' schemes[63]. Little information exists on specific woodland-related payments under the HLS because money spent on fencing, bracken control etc. for woodland creation cannot be isolated from other uses for capital payments which do not support woodland creation. An estimate from the Forestry Commission in 2010-11 was that about 516ha of

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61 http://www.forestry.gov.uk/pdf/EWGSSupportExistingWoodlandsV1.120220.pdf/$file/EWGSSupportExistingWoodlandsV1.120220.pdf

62 A recent survey of those who had planted trees under the RDPE showed that the main reason for planting was to improve habitats for wildlife with secondary reasons around improving the landscape and addressing climate change (URS, 2012).

63 Please refer to URS (2012) p.74 for a list of these schemes.

woodland was created by HLS, out of a total of 2,532 ha of woodland created under the EWGS. This is approximately 20% of the woodland created and 0.0002% of the UK's 3 million ha of woodland (URS, 2012).

The UK Forestry Standard and the UK Woodland Assurance Standard

The UK Forestry Standard (UKFS) outlines the Government's approach to sustainable forest management, with all grant aid dependent on UKFS requirements being met. The third and most recent edition of the UKFS, together with the 2011 accompanying guidelines, set a number of requirements[64] for maintaining and enhancing the resilience of forests and forest ecosystems against the risks posed by climate change.

In parallel with the UKFS, independent schemes of certification have been introduced. Certification of Sustainable Forestry Management under the UK Woodland Assurance Standard (UKWAS) is voluntary and the latest edition of the scheme is due to be approved by 1st July 2012. Although it is aimed at sustainable management in general, it could also support adaptation to climate change.

Both UKFS and UKWAS support species diversification for climate change - whether they are native or non-native is a site and objective-specific decision. There are some difficulties with species diversification as an adaptation measure on ancient woodland sites, as the palette of 'native' species from which to choose is limited. The guidance supporting adaptation will in future need to evolve to address these issues as scientific understanding improves and to avoid potential confusion over the objectives of sustainable forest management.

Keepers of Time and Ancient Woodland Practice Guidelines

The Keepers of Time and the Ancient Woodland Practice Guidelines aim to preserve the existing area of ancient woodland and increase the overall area of native woodland.

There are currently 314,000 ha of ancient woodland in England (Willis et al, 2003) which the Keepers of Time and the Ancient Woodland Practice Guidelines aim to protect. These guidelines outline management practices intended to protect ancient and native woodland in England. They pledge to ensure that the grant schemes offered by the Forestry Commission and Natural England are focused on improving ancient and native woodlands (FCE, 2005).

The ancient woodland practice guide has changed to reflect climate change adaptation thinking, recently relaxing some of the conditions on new native woodland to accommodate near native species and greater species diversification.

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[64] To achieve that high level requirement of good forest management practice, 33 guideline bullets (also covering mitigation) are provided in the UK Forestry Standard, 2011

Although this is intended to improve diversification, the guide focuses on native species and retention of native genetic diversity through the use of 'natural regeneration' and 'local provenance'. A precautionary approach to planting non-native species could reduce adaptive capacity, as the introduction of non-native species could potentially facilitate adaptation and species diversification, while protecting against the risks of invasive non-native species (FCE, 2012).

Woodland Carbon Code

The voluntary Woodland Carbon Code (launched in 2011) was developed by the Forestry Commission working with a 'Carbon Advisory Group' including representation from the forestry sector, civil society organisations and potential investors. It aims to assure potential tree-planting sponsors that their schemes meet best standards for biodiversity, ecological impact and carbon capture. It is expected to stimulate woodland creation across the UK. There is currently no target for woodland creation under the Code. The Woodland Carbon Code is intended to provide confidence in woodland carbon projects and it is anticipated that it will attract additional private finance for woodland creation, providing adaptation opportunities[65].

Woodfuel Strategy for England (2007)

The promotion of a domestic woodfuel market in the UK could promote woodland creation and management so enhancing adaptation by providing an incentive for sustainable forest management. Bringing woodlands into management encourages regeneration, evolutionary adaptation and opportunities for 'enrichment planting', species diversification and a move to more drought resilient species.

The Forestry Commission England's Woodfuel Implementation Plan (2011) and DECC's Biomass Strategy, develop sustainability criteria to protect against over-exploitation. There are, however, still some risks associated with the woodfuel and biomass agenda, with the potential for increased biomass demand to lead to poorly designed energy forests and unsustainable practices, reducing the resilience of woodlands (FCE, 2012).

Devolved Administrations

Different priorities exist for each DA, reflecting the differing nature of each DAs woodlands and forests. Some policies, such as the UK Forestry Standard, apply across the UK as a whole. The separate policies and strategies associated with the DAs are outlined below.

[65] http://www.forestry.gov.uk/forestry/INFD-8JRM37

Scotland

The Scottish Forestry Strategy (2006) set's out a framework for taking forestry forward and increasing Scotland's wood cover this century from 17% of land area at present to around 25% during the second half of the 21st Century.

The mechanisms for woodland creation in Scotland differ from those in England. The majority of creation comes from the 8 woodland creation models under the Scottish Rural Development Programme (SRDP). These models provide different levels of grants for woodland creation depending on species, location and the associated costs of planting.

There are also 6 different grants to promote sustainable forestry management, the largest of which is the Sustainable Management of Forests Grant for Restructuring Felling. This introduces payments to land-owners/managers who fell even-aged woodlands that are not well suited to current and future conditions, enhancing the woodland and landscape environment, and therefore encouraging the sustainable management of more resilient species[66].

Woodland Improvement Grants are also provided by Forestry Commission Scotland (FCS) primarily for the creation or improvement of priority habitats or species under the UK Biodiversity Action Plan.

FCS guidance has also been published in a number of areas, including seed sources for planting trees and shrubs in Scotland. Under the guidance, planting is required to promote the sourcing and use of planting stock that can maintain or enhance genetic adaptation of Scotland's tree population and consequently the ability of the stock to adapt to changing environmental conditions (Forestry Commission Scotland[67]).

Scottish Government funding has been directed at the Forest Enterprise repositioning programme that contributes substantially to forestry creation by selling FE forests and recycling the funds to acquire other suitable land that can be used for forestry.

Northern Ireland

Legal responsibility for forestry in Northern Ireland lies with the Department for Agriculture and Rural Development. The basis of Northern Ireland's forestry policy is the Forestry Act (Northern Ireland) 2010 which pledges to enhance sustainable woodland management and increase forest cover in Northern Ireland from 6% in 2006 to 12% in 2056, approximately 1700 ha a year (DARD, 2006).

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66 http://www.forestry.gov.uk/forestry/INFD-8J9H8A

67 Page accessed 30th May 2012, no publication date given: http://www.forestry.gov.uk/pdf/draftFCSCCAP08.pdf/$FILE/draftFCSCCAP08.pdf p.15

In order to deliver on these priorities, the act was rewritten to give the Forestry Service, as an agency of DARD, the relevant legislative powers to promote afforestation, to protect biodiversity and adapt to climate change.

With Northern Ireland aiming to double its woodland area from 2006 to 2056, the current level of afforestation, 500ha per annum, is not likely to be sufficient. Consequently, DARD pledged through its Strategy for Sustainable Growth and Development (2006) to use funds available under Northern Ireland's Rural Development Plan to enhance its afforestation programme. DARD has also pledged to encourage afforestation through revisions to its Woodland Grant Scheme. The Scheme is expected to continue to support all afforestation projects but will look to encourage planting in areas where forestry is particularly desirable (DARD, 2006).

Wales

There are three grants available for landowners under the **Glastir Woodland Creation scheme**. Fencing grants of £3.15 per metre are available for new planting on farm and non-farm land whilst establishment grants are also available for three years to any landowner who plants on their land, with payment dependent on size and species. A 'Woodland creation premium' is also available to farmers and non-farmers alike to compensate for income forgone. Payments can be received for up to 15 years at a rate of £300/ha/year for farmers and £66/ha/year for non-farmers[68].

Furthermore, the Glastir Woodland Management scheme offers grants to those who manage existing woodlands over 0.5ha, with grants provided for thinning, restocking, infrastructure, boundary work and pest control.

Woodlands for Wales (2009), the Welsh Government's strategy for woodlands and trees, is framed around four strategic themes that include 'responding to climate change' and 'ensuring environmental quality'. According to this strategy, the Government's first priority is ensuring that woodlands are resilient enough to adapt to climate change by increasing diversity and improving the management of woodland (FCW, 2009).

68 http://www.forestry.gov.uk/forestry/infd-6j2gxd

Annex 5 - References

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