

Climate Change Risk Assessment for the Forestry Sector

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Statement of Use

This report presents the research completed as part of the UK Climate Change Risk Assessment (CCRA) for a selected group of risks in the Forestry sector. Whilst some broader context is provided, it is not intended to be a definitive or comprehensive analysis of the sector.

Before reading this report it is important to understand the process of evidence gathering for the CCRA.

The CCRA methodology is novel in that it has compared over 100 risks (prioritised from an initial list of over 700) from a number of disparate sectors based on the magnitude of the consequences and confidence in the evidence base. A key strength of the analysis is the use of a consistent method and set of climate projections to look at current and future threats and opportunities.

The CCRA methodology has been developed through a number of stages involving expert peer review. The approach developed is a tractable, repeatable methodology that is not dependent on changes in long term plans between the 5 year cycles of the CCRA.

The results, **with the exception of population growth where this is relevant, do not include societal change in assessing future risks, either from non-climate related change, for example economic growth, or developments in new technologies; or future responses to climate risks such as future Government policies or private adaptation investment plans.**

Excluding these factors from the analysis provides a more robust 'baseline' against which the effects of different plans and policies can be more easily assessed. However, when utilising the outputs of the CCRA, it is essential to consider that Government and key organisations are already taking action in many areas to minimise climate change risks and these interventions need to be considered when assessing where further action may be best directed or needed.

Initially, eleven 'sectors' were chosen from which to **gather** evidence: Agriculture; Biodiversity & Ecosystem Services; Built Environment; Business, Industry & Services; Energy; Forestry; Floods & Coastal Erosion; Health; Marine & Fisheries; Transport; and Water.

A review was undertaken to identify the range of climate risks within each sector. The review was followed by a selection process that included sector workshops to identify **the most important** risks (threats or opportunities) within the sector. Approximately **10%** of the total number of risks across all sectors was selected for more detailed consideration and analysis.

The risk assessment used UKCP09 climate projections to assess future changes to sector risks. Impacts were normally analysed using single climate variables, for example temperature.

A final **Evidence Report** draws together information from the 11 sectors (as well as other evidence streams) to provide an overview of risk from climate change to the UK.

Neither this report nor the Evidence Report aims to provide an in depth, quantitative analysis of risk within any particular 'sector'. Where detailed analysis is presented using large national or regional datasets, the objective is solely to build a consistent picture of risk for the UK and allow for some comparison between disparate risks and regional/national differences.

This is a UK risk assessment with some national and regional comparisons. The results presented here should not be used by the reader for re-analysis or interpretation at a local or site-specific scale.

In addition, as most impacts were analysed using single climate variables, the analysis may be over-simplified in cases where the consequence of climate change is caused by more than one climate variable (for example, higher summer temperatures combined with reduced summer precipitation).

Summary

CCRA – purpose

This Climate Change Risk Assessment (CCRA) is being undertaken as part of the Adapting to Climate Change (ACC) cross government programme, based in the Department for Environment, Food and Rural Affairs (Defra). The first assessment will be laid before Parliament in January 2012 and an updated assessment will be issued every five years. The objective of the CCRA is to inform UK adaptation policy in 2012, by assessing the current and future risks and opportunities posed by the impacts of climate for the UK to the year 2100.

This report covers the forestry sector – it is one of eleven reports covering important sectors in the UK. The report explores the likely main consequences to forests and forestry from climate change. It identifies those that may have the greatest impact and by deriving ‘response functions’ with specific climatic variables, the likely risk from climate change is explored by reference to UKCIP climate projections. A preliminary assessment of costs associated with these risks has been carried out. Effects on society and the economy are summarised, and the preparedness of the forestry sector for adaptation is reviewed.

Key findings

- Forests and forestry are likely to be significantly affected by climate change over most parts of the UK, and the range and nature of goods and services provided by forests are also likely to change.
 - The risk of damaging effects from pests and pathogens is likely to increase under climate change, although it is difficult to project these effects with confidence.
 - Drought may increasingly affect tree growth and woodland ecology, particularly in the south and east of England; drought will affect timber productivity and returns on market investment.
 - There may be opportunities for the forestry sector arising from climate change, such as increased productivity because of increased temperatures in particular regions of the UK, where drought, pests, pathogens and other pressures are not limiting factors. There may also be potential benefits for some elements of woodland biodiversity.
 - The suitability of individual tree species is likely to change across the UK; adaptive management practices will change the character and ecology of woodlands, as new native and non-native species are introduced to different parts of the country.
 - Wildfires and forest fires are likely to increase in frequency although it is not possible to be confident about the size of the increase.
- The forestry sector is relatively well prepared to manage many of the risks of climate change and to instigate adaptive forest management. Forestry’s long-term nature means that the sector has had to prepare plans so that it remains sustainable in the time-scale being examined under the CCRA.

- While this study provides a useful preliminary insight, further research is essential to quantify the nature of risks from climate change, and the environmental, social and economic consequences from them.
- Climate change is just one of several drivers that could influence the future of forestry in the UK and wider change in the natural environment. This study focuses on the impacts arising from climate change. It is recognised that the impacts will also be influenced by non-climatic drivers.

Overall

Why these risks were chosen

Over 30 potential climate change impacts were identified for the forestry sector during the initial Tier 1 assessment. The following risks were chosen for the Tier 2 analysis. Their choice was a product of sector consultation and expert elicitation through, for example, the Read Report on 'Combating Climate Change: a role for UK forests' (Read *et al.*, 2009).

- Forest pests and pathogens. Past outbreaks in the UK have been largely associated with trade and imports of pests and pathogens from abroad. Evidence suggests that pest and pathogen life cycles are affected by climate; a change in climate may, therefore, cause a change in the prevalence and severity of pests and pathogens. This was identified as an important risk to examine, whilst recognising that the risk is influenced by other factors as well as climate change.
- Drought. The effect on productivity is likely to be pronounced, especially in southern and eastern Britain.
- Forest productivity. Changes in climate would almost certainly change tree growth and forest productivity – some existing woodland types are likely to be affected detrimentally, but others are likely to experience an increase in productivity. Tree species will be affected differentially, with consequences for tree species choice.
- Wildfires and forest fires. Changes in climate may affect the risk of fires, with consequences for timber production and other ecosystem services.

Emerging Challenges

This study has identified a number of challenges for understanding the potential risks and opportunities of future climate change to the forestry sector. These include:

- Assessing the areal extent of likely pest and pathogen damage by extending the use of modelling as a means of prioritising responsive action to them. It is important to consider risks specific to the particular pest or pathogen, and to attempt to relate this to its whole life cycle in future analyses.
- The degree of climate change-driven loss of productivity and the importance of translating findings into production forecasting and financial appraisal. The need to gauge likely planned adaptation measures in order to modify projections of production loss.
- The complexity of risk assessments for natural systems, where impacts are driven by multiple climate variables. More research is needed to understand and quantify the sensitivity of natural ecosystems to multiple drivers of change.

- The difficulty of capturing 'biodiversity' in risk assessment approaches like the one employed here, when there will inevitably be some gains and some losses as a complex response to climate and land management.
- Collection of data on the impacts of episodic events such as drought, waterlogging and snow/frost damage on tree growth and biodiversity.

Future risk and opportunities narrative

The risks outlined here are those that were selected for the Tier 2 analysis in this study. This report also presents an overview of the wider range of impacts that were identified in Tier 1.

Forest pests and pathogens. Forest pests and pathogens are causing increasing damage to trees, woodland and forests. Affected woodlands may experience sufficiently severe outbreaks to reduce productivity, timber quality and/or to require changing forest management. Worldwide, there is evidence that climate affects particular tree pest and pathogen life cycles and there is some evidence to show that some (but not all) past outbreaks have been associated with specific weather conditions. However, there is little evidence in the UK that past climate change has influenced pest or pathogen prevalence or severity and the dominant factor influencing spread has been international trade and imports (Read *et al.*, 2009). If climatic conditions influence the success of a pest or pathogen establishing, breeding and spreading, then a change in climatic conditions is likely to influence their prevalence and severity. A few individual species have been studied, but further research is certainly needed. This assessment assumes a causal link between climate and pest/pathogen damage and uses red band needle blight (also known as *Dothistroma* needle blight) and green spruce aphid as example species because of scientific evidence of a cause / effect link with climatic variables for these species. Nevertheless, it is recognised that these examples may not represent other pest or pathogen behaviour.

The analysis presented in this report indicates that by the 2020s, potentially 12% to 25%¹ (estimate range from 11% to 98% for the p10 to p90 probability levels for the medium emissions scenario) of pine forest area in the UK may be affected by red band needle blight, with this figure rising to 49% to 98% (range of 11% to 100% for the p10 probability level low emissions scenario to the p90 probability level high emissions scenario) in the 2050s and 100% (range of 12% to 100% for the p10 probability level low emissions scenario to the p90 probability level high emissions scenario) in the 2080s. The area extent of spruce forest in the UK that is affected by green spruce aphid is unlikely to change above the baseline as a result of climate change up to the 2020s. By the 2050s, 13% to 26% (range of 9% to 26% for the p10 probability level low emissions scenario to the p90 probability level high emissions scenario) of spruce forests may be affected by green spruce aphid. By the 2080s, 13% to 26% (range of 9% to 52% for the p10 probability level low emissions scenario to the p90 probability level high emissions scenario) of spruce forests may be affected by green spruce aphid. Significantly lower yields and higher tree mortality may result in the tree species that are affected by pests and pathogens.

Drought. Drought already affects tree physiology and woodland ecology in dry periods, but climate change projections suggest that considerable areas of the UK are likely to be progressively affected in the future. Economically, increases in drought would reduce timber productivity and returns on market investment, and may help to determine at a regional or even local level where new woodland is situated. Environmentally, the largest effects would be on woodland habitat for particular fauna

¹ These values are for the medium emissions, p50 probability level climate change scenario.

and flora; in addition, drought may increase the susceptibility of some tree species to attack by pests and pathogens. Furthermore, drought may increase the risk of wildfire. Direct effects on society are likely to be subtle, with most impact resulting from the changing visual appearance of woodlands.

The preliminary analysis presented in this report shows that the baseline loss of yield from drought (i.e. losses currently experienced) is approximately 14% in south-east England and 10% in Wales and northern Scotland. By the 2020s, yield loss caused by drought is estimated to increase approximately by an additional 2% in each of these regions. By the 2050s, there is estimated to be up to a 17% loss of yield from drought in south-east England, 16% in Wales and 14% in northern Scotland. By the 2080s, there is estimated to be up to a 19% loss of yield from drought in south-east England, 18% in Wales and a 15% loss in northern Scotland. While it is clear that effects of increased drought on productivity would not be felt uniformly across the UK, these estimates need to be checked with a more detailed analysis of drought effects on tree growth and quantification of drought risk in forest areas. In addition, the interactions with other climate changes including higher temperatures, consequent longer growing seasons and increased atmospheric CO₂ concentration need to be quantified.

Forest productivity. Using the yield class modelled by the Ecological Site Classification (ESC) tool developed by Forest Research, and current areas for important commercial tree species it has been possible to model potential production for the Forestry Commission managed public forestry estate in England, Wales and Scotland. Using UKCIP02 projections, the results for the high emissions scenario in the 2050s and 2080s show an overall decline in potential production for most conifers and broadleaves currently grown in England. For some species in some English regions the decline may be severe and would require management intervention to maintain productivity. In contrast, the ESC response function identifies significant increases in potential production in Scotland, especially for conifers, mainly as a result of increasing temperature. In Wales, some species increase in potential production whilst others decline. The projected rate of change in potential production is larger after the 2050s for most species. These projections are based on key climate, soil and tree species suitability information, and do not include interactions with other factors that may be affected by climate change, in particular pests and pathogens and increases in atmospheric CO₂.

Forest fires. The climatic conditions that promote an increase in wildfire risk such as higher temperatures, lower summer rainfall and drier soils are projected to increase over the next decades. Forest fires can endanger timber resources but pose a greater risk to wildlife habitat and recreational opportunity. An analysis of likely change in outdoor fire incidence using the McArthur Forest Fire Danger Index suggests a 30-50% increase by the 2080s (ensemble mean; medium emissions scenario) depending on country and region, with the highest risk experienced in the south of England.

Sensitivity

The early issues report for the forestry sector (Moffat and Morison, 2009) identified a range of generic issues which the department for forestry in Great Britain (Forestry Commission) judged as of equal or greater importance compared with climate change. Developing forestry policy in the devolved forestry administrations will each determine the need for, and nature of, adaptive forest management policy.

Current vulnerability

Climate change is already affecting UK forests and their management, and this is recognised in the forest adaptation strategies in all UK countries; each country is addressing adaptation in a different way depending on the perceived size of risk and the other drivers of change. Climate change effects on forestry are occurring more in

the south and east of the UK so risk is likely to be largest in these regions, if planned adaptation measures are not put in place.

Adaptive Capacity/Awareness in Sector

Adaptive capacity and general awareness of potential future climate-driven risks is high in the forestry sector. The Forestry Commission has put in place a number of important projects to enhance adaptive capacity. Awareness of relevant climate change issues is strong up to the 2050s with some now being explored into the 2080s. The awareness of climate change is high among decision takers. In addition, there is a high level of recognition of its relevance to core issues not only in the Forestry Commission but also by charities and NGOs.

The UK Forestry Standard (UKFS) and associated Guidelines are published by the Forestry Commission, supported by the Forest Service in Northern Ireland and contain important aspects of sustainable forest management. The UKFS defines the UK government's requirements for sustainable forest management and are updated regularly with an inclusive consultation process. A revised UKFS was published in November 2011, supported by new Climate Change Guidelines. Adaptation to climate change will be a requirement of the updated national forestry standard.

Interdependencies

Key links to other CCRA risks/Reports

- Trade in live plant material (including trees) is regarded as posing a particular risk for the importation of potentially damaging tree pests and pathogens, which climate change could help establish in the United Kingdom.
- Competition for land, because of changing suitability for food, farming and fibre production driven by climate change, may result in the nature and spatial extent of woods and forests changing over the next decades to an uncertain degree.
- Domestic and European energy policies may affect tree species choice if an increasing proportion of woods and forests are managed for renewable energy production from woody biomass. A number of species, including *Eucalyptus*, are being seriously considered in this regard. There is also growing interest in using novel silvicultural systems such as short rotation forestry.
- Management of woods and forests for carbon sequestration or for woodfuel supply may have consequences for biodiversity and other ecosystem services currently delivered by them.
- There is good evidence that risk of flooding can be partly alleviated by the establishment of woodland, notably in the floodplain. In contrast, water use by some tree species may affect decisions about the nature and location of new woodland in areas of the country projected to suffer shortage to water supply.
- The wide range of ecosystem services delivered by UK forests would be influenced by each of the climate change impacts identified in the Forestry Sector Tier 1 and Tier 2 Reports.
- Forests have a potential role in reducing thermal stress in watercourses. Likewise, there are clear links with the built environment and forestry's role in urban climate control and sustainable drainage.

Other Drivers

As well as climate change, the forestry sector is facing an uncertain future with regard to political and economic drivers. In response to Big Society principles, it seems likely that the relationship between policy and regulatory arms of UK government and the sector as a whole will change. There may also be changes in the balance of responsibility for managing forests between public and private sectors in some UK countries. Such developments are likely to impact on how the sector responds to climate change.

About the analysis

Data Quality and Modelling Issues

The Tier 2 analysis represents an important step forward in exploring the implications of climate change in a scientific and quantitative way, and harnesses the power of UK Climate Projections (UKCP09) appropriately. Inevitably assumptions and simplifications have had to be built into the analysis. Separation of analysis into the possible effects of single climatic variables (e.g. temperature, moisture deficit) reduces the relationship of some risks with climate to very simplistic models (e.g. pests and pathogens). Such models also ignore the relationship between the effect of climate change on (a) the biology (e.g. life cycle) of the pest or pathogen threat and (b) the phenology, physiology and biochemistry of the tree.

A further challenge in the assessment of climate change impacts in the natural environment is the non-linear nature of response. The metric for loss of productivity caused by drought is, in particular, based on analyses that assume a linear response based on past changes in conditions. In several regions of the UK, the projected change in climate extends beyond past experience and it is, therefore, not possible to draw on past data or evidence to determine what the future response of forests might be.

All risk analyses assume that the natural status of tree species distribution is fixed, but the analyses do not (and cannot with current evidence) factor in the degree to which adaptive forest management, primarily through choice of climate-suitable tree species and varieties, is likely to reduce the risks identified and quantified. Given current understanding, further supported by CCRA, such adaptation is likely to considerably reduce future risks, notably for drought. On the other hand, there is likely to be a continuing risk of pest and pathogen attack for newly introduced species. Calculation of this risk would be very difficult.

What is certain and what is uncertain

The forestry sector is fortunate in having the benefit of a recent, comprehensive review of the likely risks and impacts of climate change – the Read Report (Read *et al.*, 2009). This also focused on adaptation strategies to reduce the risks identified. The report also identified over 60 specific topics where further research was needed in order to build a sufficient evidence base for sound forestry sector decision making and operational practice in a changing climate. Many of these are already being taken forward.

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Key Term Glossary

The key terms are defined below.

Adaptation (IPCC, 2007)

- **Autonomous adaptation** – Adaptation that does not constitute a conscious² response to climatic stimuli but is triggered by ecological changes in natural systems and by market or welfare changes in human systems. Also referred to as spontaneous adaptation.

- **Planned adaptation** – Adaptation that is the result of a deliberate policy decision, based on an awareness that conditions have changed or are about to change and that action is required to return to, maintain, or achieve a desired state.

Adaptive Capacity - The ability of a system to design or implement effective adaptation strategies to adjust to information about potential climate change (including climate variability and extremes), to moderate potential damages, to take advantage of opportunities, or to cope with the consequences (modified from the IPCC to support project focus on management of future risks) (Ballard, 2009). As such this does not include the adaptive capacity of biophysical systems.

Adaptation costs and benefits

- The costs of planning, preparing for, facilitating, and implementing adaptation measures, including transition costs.
- The avoided damage costs or the accrued benefits following the adoption and implementation of adaptation measures.

Consequence - The end result or effect on society, the economy or environment caused by some event or action (e.g. economic losses, loss of life). Consequences may be beneficial or detrimental. This may be expressed descriptively and/or semi-quantitatively (high, medium, low) or quantitatively (monetary value, number of people affected etc).

Impact - An effect of climate change on the socio-bio-physical system (e.g. flooding, rails buckling).

Response function - Defines how climate impacts or consequences vary with key climate variables; can be based on observations, sensitivity analysis, impacts modelling and/or expert elicitation.

Risk - Combines the likelihood an event will occur with the magnitude of its outcome.

Sensitivity - the degree to which a system is affected, either adversely or beneficially, by climate variability or change.

Uncertainty - A characteristic of a system or decision where the probabilities that certain states or outcomes have occurred or may occur is not precisely known.

Vulnerability - Climate vulnerability defines the extent to which a system is susceptible to, or unable to cope with, adverse effects of climate change including climate variability and extremes. It depends not only on a system's sensitivity but also on its adaptive capacity.

² The inclusion of the word 'conscious' in this IPCC definition is a problem for the CCRA and we treat this as anticipated adaptation that is not part of a planned adaptation programme. It may include behavioural changes by people who are fully aware of climate change issues.

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1 Introduction

1.1 Background

It is widely accepted that the world's climate is being affected by the increasing anthropogenic emissions of greenhouse gases into the atmosphere. Even if efforts to mitigate these emissions are successful, the Earth is already committed to significant climatic change (IPCC, 2007).

Over the past century, the Earth has warmed by approximately 0.7°C ³. Since the mid-1970s, global average temperature increased at an average of around 0.17°C per decade⁴. UK average temperature increased by 1°C since the mid-1970s (Jenkins *et al.*, 2009), however recent years have been below the long-term trend highlighting the significant year-to-year variability. Because of the time lag between emissions and temperature rise, past emissions are expected to contribute an estimated further 0.2°C increase per decade in global temperatures for the next two to three decades (IPCC, 2007), irrespective of mitigation efforts during that time period.

The sorts of impacts expected later in the century are already being felt in some cases, for example:

- Global sea levels rose by 3.3 mm per year (± 0.4 mm) between 1993 and 2007; approximately 30% was due to ocean thermal expansion due to ocean warming and 55% due to melting of land ice. The rise in sea level is slightly faster since the early 1990s than previous decades (Cazenave and Llovel, 2010).
- Acidification of the oceans caused by increasing atmospheric carbon dioxide (CO_2) concentrations is likely to have a negative impact on the many marine organisms and there are already signs that this is occurring, e.g. reported loss of shell weight of Antarctic plankton, and a decrease in growth of Great Barrier coral reefs (ISCCC, 2009).
- Sea ice is already reducing in extent and coverage. Annual average Arctic sea ice extent has decreased by 3.7% per decade since 1978 (Comiso *et al.*, 2008).
- There is evidence that human activity has doubled the risk of a very hot summer occurring in Europe, akin to the 2003 heat wave (Stott *et al.*, 2004).

The main greenhouse gas responsible for recent climate change is CO_2 and CO_2 emissions from burning fossil fuels have increased by 41% between 1990 and 2008. The rate of increase in emissions has increased between 2000 and 2007 (3.4% per year) compared to the 1990s (1.0% per year) (Le Quéré *et al.*, 2009). At the end of 2009 the global atmospheric concentration of CO_2 was 387.2 ppm (Friedlingstein *et al.*, 2010); this high level has not been experienced on earth for at least 650,000 years (IPCC, 2007).

³ Global temperature trends 1911-2010 were: HadCRUT3 $0.8^{\circ}\text{C}/\text{century}$, NCDC $0.7^{\circ}\text{C}/\text{century}$, GISS $0.7^{\circ}\text{C}/\text{century}$. Similar values are obtained if we difference the decadal averages 2000-2009 and 1910-1919, or 2000-2009 and 1920-1929.

⁴ Global temperature trends 1975-2010 were: HadCRUT3 $0.16^{\circ}\text{C}/\text{decade}$, NCDC $0.17^{\circ}\text{C}/\text{decade}$, GISS $0.18^{\circ}\text{C}/\text{decade}$.

The UK Government is committed to action to both mitigate and adapt to climate change⁵ and the Climate Change Act 2008⁶ makes the UK the first country in the world to have a legally binding long-term framework to cut carbon emissions, as well as setting a framework for building the nation's adaptive capacity.

The Act sets a clear and credible long-term framework for the UK to reduce its greenhouse gas (GHG) emissions including:

- A legal requirement to reduce emissions by at least 80% below 1990 levels by 2050 and by at least 34% by 2020.
- Compliance with a system of five-year carbon budgets set up to 15 years in advance, to deliver the emissions reductions required to achieve the 2020 and 2050 targets.

In addition it requires the Government to create a framework for building the UK's ability to adapt to climate change and requires Government to:

- Carry out a UK wide Climate Change Risk Assessment (CCRA) every five years.
- Put in place a National Adaptation Programme for England and reserved matters to address the most pressing climate change risks as soon as possible after every CCRA.

The purpose of this CCRA is to provide underpinning new evidence, assessing the key risks and opportunities to the UK from climate change, and so enable the UK and Devolved Governments to prioritise adaptation options and inform current and future policy development. The CCRA will also inform devolved Governments' policy on climate change mitigation and adaptation.

Climate Change Act: First five year cycle

The Scope of the CCRA covers an assessment of the risks and opportunities to those things which have social, environmental and economic value in the UK, from the current climate and future climate change, in order to help the UK and devolved Governments identify priorities for action and implement necessary adaptation measures. The Government requires the CCRA to identify, assess, and where possible estimate economic costs of the key climate change risks and opportunities at UK and national (England, Wales, Scotland, Northern Ireland) level. The outputs from the CCRA will also be of value to other public and private sector organisations that have a stake in the sectors covered by the assessment.

The CCRA will be accompanied (in 2012) by a study on the Economics of Climate Resilience⁷ (ECR) that will identify options for addressing some of the priority risks identified by the CCRA, and will analyse their costs and benefits. This analysis will provide an overall indication of the scale of the challenge and potential benefits from acting; and, given the wide-ranging nature of possible interventions, will help to identify priority areas for action by Government on a consistent basis.

This will be followed by the first National Adaptation Programme (NAP). The NAP will set out:

- objectives in relation to adaptation
- proposals and policies for meeting those objectives

⁵ <http://www.defra.gov.uk/environment/climate/government/>

⁶ <http://www.legislation.gov.uk/ukpga/2008/27/contents>

⁷ <http://www.defra.gov.uk/environment/climate/government/>

- timescales
- an explanation about how those proposals and policies contribute to sustainable development.

The CCRA analysis has been split into eleven sectors to mirror the general sectoral split of climate impacts research; agriculture, biodiversity and ecosystem services, business, industry and services, built environment, energy, floods and coastal erosion, forestry, health, marine and fisheries, transport and water.

1.2 Scope of the Forestry Sector Report

This report presents the results of the Climate Change Risk Assessment (CCRA) Tier 2 for the forestry sector. The forestry sector covers trees, woodlands and forests in the UK and it embraces all their uses and benefits, including the timber production industry, their value as part of the natural environment and the recreation and amenity resource they provide to society. The potential impacts of climate change on the forestry sector have wider consequences than for this sector alone and there are particularly clear links with the biodiversity and ecosystem services, business, industry and services and health sectors considered in the CCRA process.

A change in climate can result in a range of impacts and consequences including increased tree damage and vulnerability to attack from pests and pathogens, reduced tree growth and reduced supply of high-quality timber, loss of habitat, biodiversity and threats to important woodland species, loss of recreational areas and reduced quality of natural spaces and disruption to local infrastructure, communities and businesses. There may also be positive impacts, for example, longer growing seasons and increased productivity. This report details the identification and assessment of these and other potential impacts.

The forestry sector is influenced by many other drivers and pressures including, for example, the Common Agricultural Policy and Rural Development Policy; the existing and changing UK regulatory environment; fluctuating global markets for timber and timber processing; management and recovery from countryside access restrictions (e.g. Foot and Mouth outbreaks); and societal perceptions of the forestry industry. Climate change risks and adaptation responses must be considered in this wider context.

1.3 Overview of the UK Forestry sector

Woodland area has expanded greatly over the past 90 years, increasing from 5% of the total land area of the UK in 1924 to 13% in 2010 (equal to 3.07 million hectares). Woodland covers 10% of the land area in England, 18% in Scotland, 15% in Wales and 6% in Northern Ireland according to the Forestry Commission (2010; 2011a). There is substantially less woodland cover in the UK in comparison to the global average of 31% and the EU average of 37% (FAO, 2010).

There are major concentrations of planted coniferous woodlands in Wales, south and west Scotland, Northumberland, and East Anglia. The Scottish Highlands have significant cover of native woodland as does the New Forest, Forest of Dean/Wye Valley and the south-east of England. Elsewhere native woodland is largely fragmented.

Climate, soils, land availability and productive potential have all influenced the location of plantations and the selection of species within them (Quine *et al.*, 2011). In the 20th

century, Sitka spruce (*Picea sitchensis*) was the dominant choice of commercial species in northern and western areas, with large areas of forest planted on upland heaths and grasslands. Scots pine (considered native only to Scotland) and Corsican pine (*Pinus nigra* ssp. *laricio*) were more popular in the south and east, but Douglas fir (*Pseudotsuga menziesii*) and various species of larch and other conifers were also planted extensively across the UK. Sitka spruce is the commonest tree species in Britain (26% by area) followed by Scots pine (8.5%) and oak (8.4%) (Table 1.1). In Northern Ireland, Sitka spruce accounts for the largest volume of growing stock (6.5 million m³ in 2010), followed by Scots pine (0.7 million m³), Norway spruce (0.5 million m³) and oak (0.4 million m³) (FAO, 2010). The great majority of woodland in the UK is managed as high forest, with clear-felling and restocking on a 40- to 50-year rotation for conifers. Thinning of woodland has been limited because of the increased threat of wind throw after thinning and by lack of markets for small dimension products. The small amount of coppicing (0.9% by area) that takes place in the UK is undertaken almost exclusively in England. Coppicing was much more extensive in the past; for example, in 1948 the majority of woods in England were classified as coppice or coppice with standards.

Table 1.1 Area of woodland in GB by main tree species ('000 ha)

Source: Forestry Commission (2003).

Species	England	Scotland	Wales	GB*
Conifers				
Scots pine	82	140	5	227
Corsican pine	41	2	3	47
Lodgepole pine	7	122	6	135
Sitka spruce	80	528	84	692
Norway spruce	32	35	11	79
European larch	14	9	1	23
Japanese/hybrid larch	33	56	22	111
Douglas fir	24	10	11	45
Other conifer	19	5	6	30
Mixed conifer	9	8	0	18
Total conifers	340	916	149	1406
Broadleaves				
Oak	159	21	43	223
Beech	64	10	9	83
Sycamore	49	11	7	67
Ash	105	5	19	129
Birch	70	78	13	160
Poplar	11	0	1	12
Sweet chestnut	12	0	1	12
Elm	4	1	0	5
Other broadleaves	84	18	18	120
Mixed broadleaves	91	62	8	160
Total broadleaves	648	206	118	971
Total – all species	988	1123	266	2377
Felled	15	23	9	47
Coppice†	22	1	0	24
Open space‡	72	134	11	217
Total woodland	1097	1281	287	2665

*Note no equivalent data are available for Northern Ireland

†Coppice includes coppice with standards

‡Areas of integral open space, each <1ha

The UK has no primary woodland left, but approximately 552,000 hectares of ancient woodland remain in the UK, which is defined as areas that have been continuously wooded since at least AD 1600, or AD 1750 in Scotland (Forestry Commission, 2009a). Of this, 329,000 hectares are classified as 'Ancient and Semi Natural Woodland' and 223,000 hectares as 'Plantations on Ancient Woodland Sites'. The removal of planted exotic species from 'Plantations on Ancient Woodland Sites' (so-called PAWS) has been an aim in recent years. There has also been some restoration of peat bog from afforestation, and continued pressure for woodland removal from other valued habitats, notably lowland heath.

The public forest estate amounted to 28% of the total woodland area of the UK in 2008. This proportion ranged from 18% of the woodland area in England to 70% in Northern Ireland. Other owners include traditional estates and investment and management companies (Forestry Commission, 2008). Conservation charities such as the National Trust and Woodland Trust have also developed their land holdings to play a significant part in woodland management (with 25,000 and 20,000 hectares respectively).

Figure 1.1 shows where the main wooded areas are in Great Britain. Some regions have very low woodland cover, such as Cambridgeshire (4%) and Lincolnshire (3%), but others are comparatively well wooded, for example east Galloway (nearly 36%), Surrey (nearly 22%) and south Gwynedd (nearly 20%).

Figure 1.2 shows the age distribution of tree stands in Great Britain for conifer and broadleaved types. It reflects the significant planting programmes that took place in the second half of the twentieth century, which involved both replanting areas felled during WWII and expansion onto marginal agricultural land. However, it also shows that this level of planting has not been sustained in the past twenty years, and that a large proportion of the forest is approaching optimal harvesting age (approximately 40-60 years for productive conifer species such as Sitka spruce).

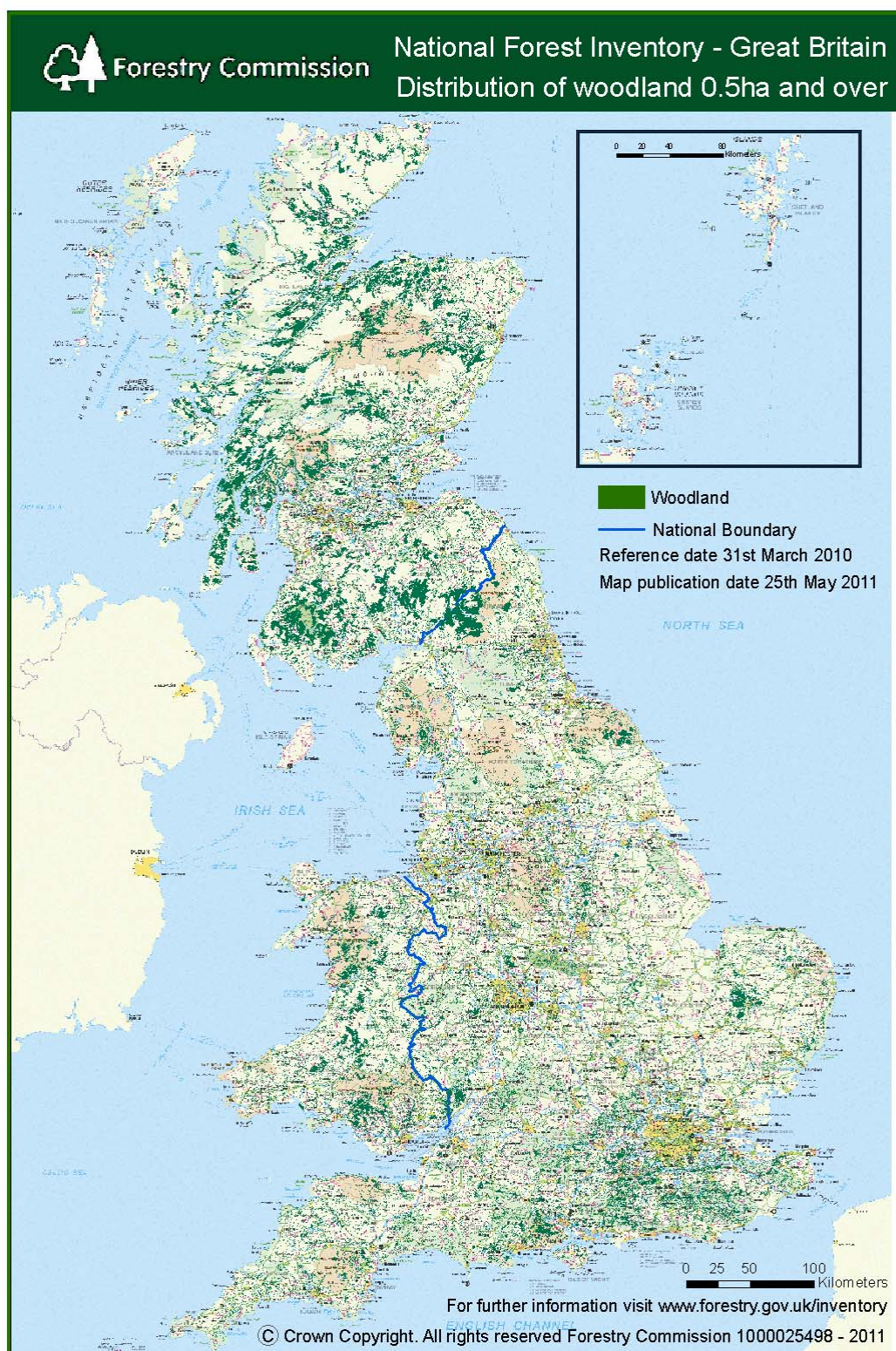


Figure 1.1 Distribution of woods and forests in Great Britain in 2010
(from [http://www.forestry.gov.uk/pdf/GB_Map.pdf/\\$FILE/GB_Map.pdf](http://www.forestry.gov.uk/pdf/GB_Map.pdf/$FILE/GB_Map.pdf))

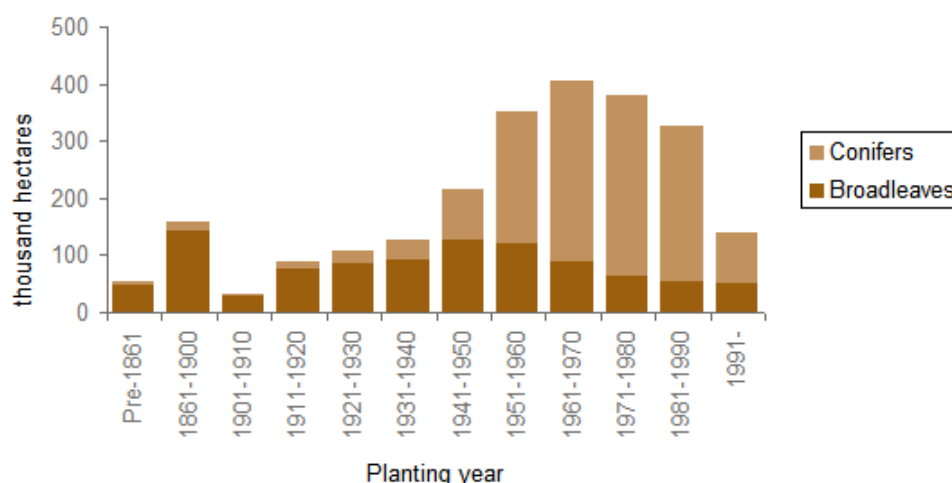


Figure 1.2 Age profile of woodland in GB
(from Forestry Commission, 2010)

Table 1.2 shows estimated standing timber volumes by woodland type and species. Commercial coniferous species provide the majority of timber stocks. They are all non-native with the exception of Scots pine. Most planted forests and the majority of managed woodlands are predominantly of one or two tree species.

Table 1.2 Growing stock in 2010 by ownership, type and species (million cubic metres)
(from FAO, 2010)

Common name	GB Private comm forecast	GB Private non- comm	GB Private over- mature comm	GB Private over- mature non- comm	GB State comm	GB State non- comm	GB Total	NI	UK Total
Sitka spruce	72.9	0.3	3.2	0.0	54.4	0.6	131.4	6.5	137.8
Scots pine	25.8	0.8	8.0	0.7	9.2	0.4	44.9	0.7	45.6
Larch	9.9	0.4	2.6	0.1	5.4	0.3	18.9	0.3	19.2
Lodgepole pine	13.1	0.1	0.1	0.0	8.3	0.2	21.8	0.3	22.1
Norway spruce	10.3	0.2	0.9	0.0	5.7	0.3	17.4	0.5	17.9
Douglas fir	6.2	0.1	1.6	0.0	3.0	0.0	10.9	0.2	11.0
Corsican pine	3.8	0.0	0.6	0.1	4.6	0.1	9.2	0.0	9.3
Other conifers	5.7	1.0	4.9	3.1	2.8	0.2	17.8	0.2	18.0
Total conifers	147.6	2.9	22.0	4.1	93.5	2.2	272.3	8.7	281.0
Oak	15.3	6.0	4.8	0.8	1.1	0.3	28.3	0.4	28.7
Beech	6.8	1.1	6.4	1.1	1.6	0.1	17.2	0.1	17.3
Birch	2.1	3.9	0.7	0.4	0.0	0.3	7.3	0.2	7.5
Ash	4.9	1.4	5.9	2.1	0.0	0.1	14.4	0.1	14.5
Sycamore	2.3	0.9	2.2	0.9	0.1	0.5	6.7	0.1	6.8
Other broadleaves	10.5	8.3	2.4	0.7	0.2	0.6	22.8	0.2	23.1
Total broadleaves	41.9	21.5	22.5	5.9	3.0	1.9	96.7	1.1	97.8
TOTAL	189.5	24.5	44.4	10.1	96.5	4.1	369.0	9.8	378.8

comm, comml = commercial; non-comm = non commercial (see FAO, 2010)

Biologically, annual wood production (the 'annual increment') has exceeded the annual harvest for many years (about 60% and 20% for conifers and broadleaves, respectively, Forestry Commission, 2002). While the Forestry Commission aims to balance the volume harvested with the increment for the public estate, this does not apply to privately owned woodland. UK production of roundwood totalled 8.5 million m³ wood raw material equivalent underbark (WRME) in 2009. A further 39.5 million m³ WRME of wood and wood products were imported to the UK in that year, while 4.2

million m³ WRME were exported. These figures exclude recycled wood and recovered paper. The main markets for timber and wood-based products are construction, pallets and packaging, furniture, fencing and outdoor use markets. In addition, there is a wide selection of other markets, ranging from the manufacturing of kitchen utensils, picture frames and toys to ladders and transport components.

More recently, biomass energy for industrial, commercial and domestic purposes has emerged as a potentially substantial market for UK wood (Moffat *et al.*, 2010). Of approximately 10 million tonnes of wood harvested from UK woodlands each year⁸, 0.1 million green tonnes (MGT) were delivered to energy markets in 2006, increasing to 1.05 MGT by 2010. In addition a further 0.1 MGT of brash and stumps were supplied. Fuel markets accounted for 75% of hardwood deliveries in 2010 and this market is underpinning the management of broadleaved woodland in some areas of the UK. Demand for firewood for use in stoves is also increasing.

The Renewable Heat Incentive, due for launch in November 2011⁹ is likely to significantly increase demand for woodfuel. If projected deployment is realised this market could account for 15 MGT of wood annually by 2020. The 2011 Woodfuel Implementation Plan published by Forestry Commission England¹⁰ aims to use this developing market to bring an additional 2 MGT of wood to the market annually from privately owned, presently under-managed woodlands. This is estimated to be around 50% of unharvested annual increment in England. Increasing forestry production in Scotland and Wales could, perhaps, provide an additional 1 to 1.5 MGT of woodfuel.

Wood accounted for around half of the 5 million tonnes of biomass used for power generation in 2010¹¹, including recycled wood, imported pellets, short rotation coppice and sawmill co-products. Projected large increases of biomass for power generation¹² over the next 20 years imply an additional annual fuel requirement equivalent to around 50 MGT of wood. In practice many other biomass feedstocks will be used as fuel and it is likely that imports will dominate supply chains. Furthermore, if technologies used to produce ethanol¹³ and synthetic diesel¹⁴ from woody feedstocks become commercially viable there may be additional demand for wood.

The ownership profile for UK woods and forests is summarised in Figure 1.3. It shows that over half is owned by individuals or families, with only 13% in the hands of private institutions, suggesting a fragmented ownership pattern in the private sector. It has been estimated that there are over 100,000 woodland holdings in the UK¹⁵. The proportion of state-owned and managed forest and woodland was 28% in 2010 (Forestry Commission, 2010).

⁸ UK Wood production and trade (provisional figures) May 2011

[http://www.forestry.gov.uk/pdf/trprod11.pdf/\\$FILE/trprod11.pdf](http://www.forestry.gov.uk/pdf/trprod11.pdf/$FILE/trprod11.pdf) [accessed 04/10/11]

⁹ Renewable Heat Incentive page on Biomass Energy Centre website

[http://www.forestry.gov.uk/pdf/trprod11.pdf/\\$FILE/trprod11.pdf](http://www.forestry.gov.uk/pdf/trprod11.pdf/$FILE/trprod11.pdf) [accessed 04/10/11]

¹⁰ Forestry Commission England Woodfuel Implementation Plan 2011 – 2014 <http://www.forestry.gov.uk/england-woodfuel> [accessed 04/10/11]

¹¹ Ofgem Annual Sustainability Report 2010/11

<http://www.ofgem.gov.uk/Pages/MoreInformation.aspx?docid=318&refer=Sustainability/Environment/RenewableObl/FuelledStations> [accessed 04/10/11]

¹² Review of the generation costs and deployment potential of renewable energy technologies in the UK

http://www.decc.gov.uk/assets/decc/What%20we%20do/UK%20energy%20supply/Energy%20mix/Renewable%20energy/policy/renew_obs/1834-review-costs-potential-renewable-tech.pdf

¹³ Lignocellulosic conversion to bioethanol page on BBSRC Sustainable Bioenergy Centre website

<http://www.bsbec.bbsrc.ac.uk/programmes/lignocellulosic-conversion-to-bioethanol.html> [access 04/10/11]

¹⁴ Gasification page on Biomass Energy Centre website

http://www.biomassenergycentre.org.uk/portal/page?_pageid=75.17504&_dad=portal&_schema=PORTAL [accessed 04/10/11]

¹⁵ [http://www.forestry.gov.uk/pdf/soefind6.1.pdf/\\$FILE/soefind6.1.pdf](http://www.forestry.gov.uk/pdf/soefind6.1.pdf/$FILE/soefind6.1.pdf)

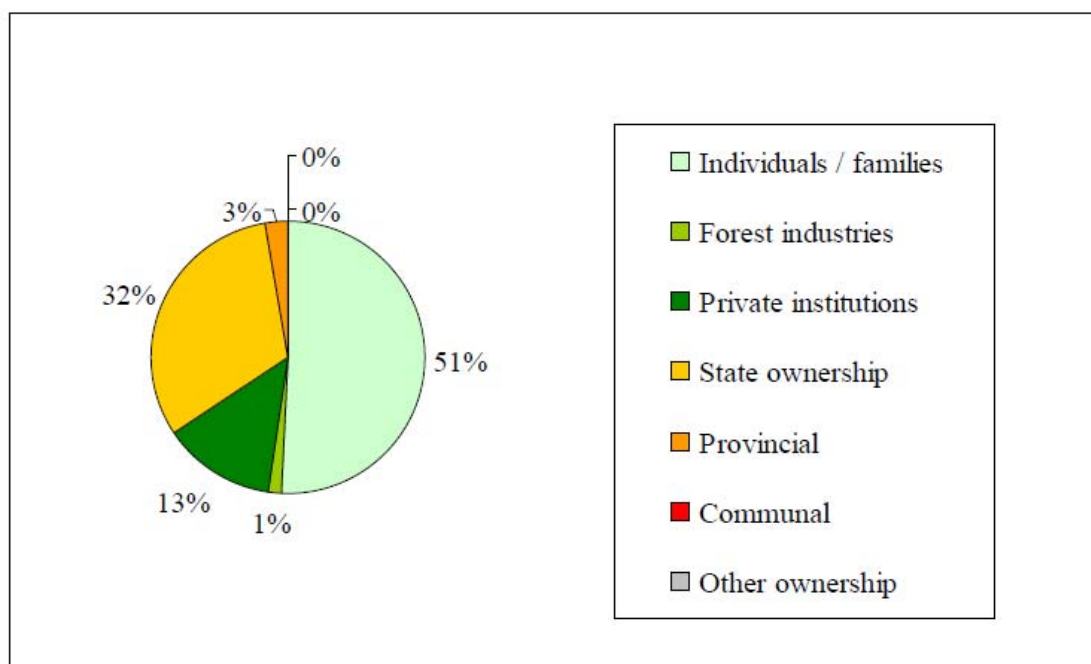


Figure 1.3 Ownership of UK woodland and forests in 2005

(from Schmithüsen and Hirsch, 2010)

A substantial wood processing industry has been established, and the UK exports wood-based products. But the UK is also a major importer of wood-based products, sixth in the world in value terms. The Gross Value Added for forestry and primary wood processing, the difference between the value of outputs and the value of intermediate consumption, was over £1.9 billion in 2008 (Forestry Commission, 2009a). This excludes secondary wood processing industries, which are mainly based on imported materials.

In 2008, 41,000 people were employed in the UK forestry and primary wood processing sectors (Forestry Commission, 2009a). Of these, there were 12,000 employed in the forestry, logging and related services plus another 11,000 in sawmilling and 5,000 producing panels, although only about 6,000 full-time equivalents are estimated to be reliant on UK-sourced wood.

Forests provide a wide range of ecosystem goods and services (Quine *et al.*, 2011). This role is reflected in the definition of Sustainable Forestry Management, and the Ecosystems Approach adopted by the UK National Ecosystem Assessment (2011). Table 1.3 gives a brief list of the services considered most important.

Table 1.3 Types of ecosystem service provided by trees, woodlands and forestsAdapted from Quine *et al.* (2011).

Ecosystem services	Examples of goods and benefits in the UK
PROVISIONING	
Crops, livestock and fisheries	Production from agroforestry and some wood-pasture systems and collection of non-timber forest products (NTFPs), e.g. meat, berries, honey, fungi, and medicinal derivatives.
Trees for timber	Provision of raw materials for use in wood products, boards and paper. Timber as a low carbon alternative to other building materials such as steel.
Trees for bio/woodfuel	Timber products (e.g. harvesting residues, stumps and roots, recycled wood) as fuel for heat and power plants, as domestic firewood, for biochar and biofuels.
Woodlands and water supply	Wooded catchments especially in the uplands provide important water supplies for major urban areas.
REGULATING	
Climate	Avoidance of climate stress. Tree cover can help protect soils, surface waters, animals and humans from extremes of temperature, strong winds and UV light.
	Carbon sequestration. Woodlands and their soils are important reserves of terrestrial carbon, and timber products can also be considered.
Hazard	Soil protection. Tree cover can protect against soil erosion and slope failure. Reduced exposure to chemicals and pesticides and likelihood of soil compaction compared to agriculture.
	Flood and water protection. Woodlands moderate rainfall events and river and stream hydrographs, delaying and reducing flood events.
Disease and pests	Woodland dwelling organisms can help to regulate the incidence and spread of insect pests and pathogens of importance to humans, crops and ecosystems
Detoxification and Purification	Water quality. Because of minimal use of pesticides and fertilisers, woodlands managed under sustainable principles also offer benefits of water quality.
	Soil quality. Woodland cover can stabilise contaminated brownfield land and hinder the pathways between source and receptors.
	Air quality. Capture of atmospheric pollutants in tree canopies can lead to consequent reduced exposure for humans, crops, buildings etc.
	Noise reduction. Belts of trees between residences and transport routes can absorb sound.
Pollination	Woodlands provide habitat for diverse wild pollinator communities of importance to trees, crops and other plants.
CULTURAL	
Wild species diversity	Biodiversity. UK forests, including plantations, provide habitat for a wide range of fauna and flora but a limited genetic resource (c.f. tropical forests).
Local places	Trees and woodlands are valuable for personal enlightenment and as places or catalysts for social activity and cohesion.
	Forests are increasingly acknowledged for their educational value.
	Trees have been perpetual motifs in fine art, and influenced many other art forms.
Landscapes/seascapes	Many forests provide for the enjoyment of outdoor pursuits and recreational activities. Their access facilitates exercise and benefits human health.
	Trees and woodlands increase the diversity of landscape character; their existence provides a link with the past; woodlands reduce the need for cultivation, a significant cause of archaeological destruction.
SUPPORTING	
Soil and atmosphere,	Forests facilitate soil formation and other biogeochemical processes such as nutrient, water and oxygen cycling essential to life.
Biodiversity	Locally adapted provenances, distinctive assemblages associated with some species being at the edge of range and a distinctive maritime climate.

A key ecosystem service that forests provide is the 'regulating service' for climate. UK forests contribute to climate change mitigation primarily through their role in the UK GHG balance. The stock of carbon in UK woodlands and forests is currently estimated at 878 MtC, (equivalent to 3219 Mt CO₂) and approximately 75% of this stock is contained in the soil (to a depth of 1 m; Morison *et al.*, 2011). UK forests absorb a substantial amount of CO₂ from the atmosphere. Net CO₂ uptake by UK forests has been estimated at between 9 and 15 Mt CO₂ y⁻¹, which is only approximately 2-4% of national annual CO₂ emissions. The UK Climate Change Act 2008 set a legally binding target to reduce the UK's emissions of GHGs to at least 80% below 1990 levels by 2050 (i.e. to < 155 Mt CO₂e y⁻¹), which if the reduction applied to CO₂ alone would imply CO₂ emissions <120 Mt CO₂ y⁻¹. Thus forestry policies and practices which increase the net flux of CO₂ into forests could make a significant contribution to the UK GHG balance. Similarly changes to UK climate that affect the extent, productivity or management of UK forests could have significant effects on the GHG balance.

Forests are now regarded as important for delivering on many government agendas, such as improving quality of life, tackling social exclusion, and promoting sustainable lifestyles. Increasing urbanisation and the impact of community forests has brought the public benefits of forests into sharp focus in recent years. Forests, including urban woodlands, have a key role in delivery of 'green health' benefits, by providing attractive areas for exercise and restorative post-stress environments with consequent physical and mental health benefits (Quine *et al.*, 2011). People have significant cultural and social attachments to trees and woods, and value them as components of the UK landscape. They also have a key role in the delivery of wider recreation opportunities, both formal and informal. Forests are increasingly popular as destinations for sport, leisure and tourism. Around two-thirds of the UK population have visited forests in the past few years (Forestry Commission, 2011a), and it is estimated that there were 326 million visitors to English forests and woodlands in 2010-11 (Forestry Commission, 2011a). Forests also have an important role in environmental education, (e.g. over 150 Forest Schools have been set up; Knight, 2009), and they have potential for contributing to the public understanding of climate change. There is a strong connection in many people's minds between the presence of forests and climate change mitigation. In many UK regions, they are integral to the rural economy and social enterprise.

1.4 Current policy landscape

The statutory basis for forestry in the UK is contained in the Forestry Act 1967. This charged the Forestry Commission "with the general duty of promoting the interests of forestry, the development of afforestation and the production and supply of timber and other forest products." It also promoted the "establishment and maintenance...of adequate reserves of growing trees." However, forestry policy has evolved from one primarily focused on home-grown timber production to one which incorporates multiple objectives. Today it is centred on the principle of 'Sustainable Forest Management' (Forestry Commission, 2004; 2011d). This is the global forest industry response to sustainability principles which emerged from the United Nations Conference on Environment and Development (the Rio Earth Summit) in 1992. The Second Ministerial Conference on the Protection of Forests in Europe in Helsinki, 1993 defined Sustainable Forestry Management as:

"the stewardship and use of forests and forest lands in a way, and at a rate, that maintains their biodiversity, productivity, regeneration capacity, vitality and their potential to fulfil, now and in the future, relevant ecological, economic and social functions, at local, national, and global levels, and that does not cause damage to other ecosystems".

This multifunctional approach to forestry is central to the modern delivery of forestry policy in the UK, both in the management of the public forest estate (28% of all UK woodland and forest), and in the development of requirements for planning, designing and managing forests for private woodland owners to follow. These are contained in the UK Forestry Standard (Forestry Commission, 2004; 2011d) and its supporting guidelines. The Guidelines also have an important function as the basis of forestry practice for the independent UK Woodland Assurance Standard (UKWAS), which is used for the voluntary independent certification of Sustainable Forestry Management. The public forest estate in Great Britain has been certified under this scheme since 2000. In 2008, 45% of all UK woodland was certified.

The UK Government devolved responsibility for forestry to Scottish Ministers and the National Assembly for Wales in 1999 as part of a wider programme of constitutional reform. It retained responsibility for forestry in England and for international issues. Forestry has been fully devolved in Northern Ireland since 1922. A consequence of devolution has been the development of different Forestry Strategies for Scotland and Wales (Scottish Executive, 2006; Welsh Assembly Government, 2009). These set out the priorities and programmes of the devolved administrations for developing and implementing forestry policy over the next few decades, and are distinctly different, in part reflecting the nature of each country's woodland and forests.

1.4.1 Scottish forest policy

In Scotland, forestry policy is set within the broad context of growing the economy in a sustainable way to raise quality of life. The Scottish Forestry Strategy's core principles are based on sustainable development and social inclusion, achieved through a culture of 'forestry for and with people' and delivered in well managed forests and woodlands that integrate effectively with other land uses and businesses (Scottish Executive, 2006).

Seven key policy themes have been chosen to deliver the vision above:

- Using forestry, and adapting forestry practices, to help reduce the impact of climate change and help Scotland adapt to its changing climate.
- Getting the most from Scotland's increasing and sustainable timber resource.
- Strengthening forestry through business development to underpin sustainable forest management and support economic growth and employment across Scotland.
- Improving the quality of life and well-being of people by supporting community development across Scotland.
- Making access to, and enjoyment of, woodlands easier for everyone - to help improve physical and mental health in Scotland.
- Protecting the environmental quality of our natural resources (water, soil and air), contributing to and improving our scenery, and helping to make the most of our unique historic environment.
- Helping to restore, maintain and enhance Scotland's biodiversity, and increasing awareness and enjoyment of it (Scottish Executive, 2006).

Scottish forestry policy seeks to encourage the effective integration with other land uses, and with sectors such as energy, transport, health, water, education and tourism, to get the most out of these key themes.

Forestry policy in Scotland recognises the specific role of forests in tackling climate change, and has identified several actions for Forestry Commission Scotland, namely:

- Protecting and managing existing forests through sustainable forest management, conserving carbon stocks, and minimising woodland removal (Scottish Government, 2011a).
- Creating new woodland to capture carbon, produce wood and help adaptation. There is a policy to increase the tree planting rate to 10,000 ha per year and maybe towards 15,000 ha per year (Scottish Government, 2011a).
- Adapting to climate change by planning and managing forests and woodlands in a way that minimises future risks from climate change, for example through the creation of forest habitat networks, and using different timber species, including hardwoods, or silvicultural systems.
- Promoting the use of sustainably produced wood for energy and construction.
- Reducing the forestry sector's carbon footprint.
- Raising awareness and understanding of climate change and how forestry can make a positive contribution.
- Measuring progress (Forestry Commission Scotland, 2009).

The Scottish Land Use Strategy (Scottish Government, 2011b) also proposes action for climate change adaptation which is relevant to forests and the forestry sector. A review of Scotland's approach to the Common Agricultural Policy, including the role of Scotland's Rural Development Programme in supporting climate change objectives through forestry measures, is being undertaken in the lead up to the next Rural Development Programme period which starts in 2014.

An analysis of preparedness for adaptation in the Scottish forestry sector (Scottish Government, 2011c) considered that it has 'a strong platform to start from' based on existing policies and their likely, near-future, development.

1.4.2 Welsh forestry policy

Wales' forestry strategy, Woodlands for Wales¹⁶, has four strategic themes, one of which is 'Responding to climate change'. This theme focuses on striking a balance between substitution of more fossil-fuel intensive substances with wood (for example in building construction or as fuel) and carbon sequestration and retention in woodlands, through the creation of new woodlands, conforming to the UK Forestry Standard, and maximising existing woodland carbon storage capacity. In March 2010, following recommendations from the Land Use and Climate Change Group, the Welsh Government confirmed its target to create 100,000 hectares of new woodland in Wales by 2030 via the Glastir¹⁷ scheme.

¹⁶ <http://wales.gov.uk/topics/environmentcountryside/forestry/woodlandsforwales>

¹⁷ <http://wales.gov.uk/topics/environmentcountryside/farmingandcountryside/farming/glastirhome/>

Woodlands for Wales moves Wales towards more mixed and native woodland, and reduces reliance on clearfelling regimes. It acknowledges the challenge of how best to adapt woodlands to climate change, while at the same time promoting trees, woodlands and timber as part of the solution to reducing greenhouse gas emissions. It also recognises the challenge in rediscovering expertise in managing mixed woodlands for high quality timber products (Forestry Commission Wales, 2011).

As the Climate Change Strategy for Wales¹⁸, acknowledges, the forestry sector has a key role to play in helping Wales adapt to the negative effects of climate change, such as loss through the loss of biodiversity and disrupted hydrological patterns. The forestry sector is also making a wider contribution to sustainable development objectives by providing places of recreation, learning, community development and health promotion. The forestry sector is also playing a major role in delivering the Welsh Government's renewable energy policy where wind farm developments are integrated into the management of the public forest estate.

1.4.3 Northern Ireland forestry policy

The basis for modern forestry policy in Northern Ireland is the Forestry Act (Northern Ireland) 2010. Specific policy areas are identified in the Delivery Plan (DARD, 2011) which describes actions to be taken in support of delivering against these policy objectives.

The Forestry Act is inextricably linked to the Forestry Strategy, articulated in "Northern Ireland - a Strategy for Sustainability and Growth" (DARD, 2006). The Forestry Strategy is built around twin policy pillars:

- The sustainable management of existing woods and forests
- A steady expansion of tree cover to increase the many diverse benefits that forests provide.

The Forestry Act addresses the Department's contemporary and evolving commercial, environmental and social objectives for forestry and allows it to obtain better value from the forest estate. Importantly, the Forestry Act promotes sustainable forestry and the management and development of forests to contribute to the protection of the environment, biodiversity and the mitigation of, or adaptation to, climate change.

Eight key themes support the twin pillars of afforestation and sustainable forestry:

- Forest Expansion
- Timber Production
- Management and Development of Forests
- Protection of the Environment
- Climate Change
- Recreational and Social Use
- Partnership Development
- Commercialisation.

The principal policies to support Northern Ireland's responsibilities for climate change mitigation and adaptation are to:

¹⁸ <http://wales.gov.uk/topics/environmentcountryside/climatechange/tacklingchange/strategy/walesstrategy/>

- Encourage the expansion of tree cover to mitigate climate change
- Promote supply of wood for industrial use and in support of renewable energy opportunities
- Promote a Short Rotation Coppice grant scheme for planting of tree crops for renewable energy purposes
- Encourage renewable energy on forest land
- Plant and promote the planting of trees that can adapt to changing climate
- Raise awareness of the potential impacts of climate change and the role of forestry in mitigation and adaptation.

To help deliver within the climate change theme, a Climate Change branch has been established to develop mitigation strategies, and DARD's Forest Service has an acknowledged contribution. Climate change policy in Northern Ireland is further informed by a detailed review (Arkell *et al.*, 2007).

1.4.4 English forestry policy

In March 2011, the Secretary of State for the Environment announced the terms of reference for an Independent Panel on Forestry to advise on the future direction of forestry and woodland policy in England. It was given the remit¹⁹:

1. To advise the Secretary of State for Environment, Food and Rural Affairs on the future direction of forestry and woodland policy in England.
2. To advise on the role of the Forestry Commission in implementing policy on forestry and woodland in relation to England.
3. In formulating this advice, the Panel should consider:
 - a. how woodland cover can be increased, given competing pressures on land use for food production, energy and development
 - b. options for enhancing public benefits from all woodland and forests, in the light of the Lawton Report and the Natural Environment White Paper, including:
 - public access for recreation and leisure
 - biodiversity, wildlife protection and ecological resilience, including through restoration of open habitats and plantations on ancient woodland sites
 - climate change mitigation and adaptation
 - economic development, particularly to support a sustainable timber industry and a wide range of small and medium sized enterprises, including social enterprises
 - engagement and participation of civil society
 - c. constraints and competing demands on public expenditure for this Spending Review period and beyond

¹⁹ <http://archive.defra.gov.uk/rural/forestry/documents/forestry-panel-tor2.pdf>

- d. the role of Forest Enterprise England as the manager of productive forestry resources
 - e. the value for money and cost-effectiveness of the public forest estate in England and options for its future ownership and management.
4. In formulating its advice to the Secretary of State, the Panel will be expected to engage and take evidence from the widest range of views and interest.
 5. The Panel will report to the Secretary of State in April 2012, with a progress report in the autumn of 2011.

The Natural Environment White Paper, published in June 2011 (Defra, 2011) makes specific reference to forestry policy in respect of seeking a major increase in the area of woodland in England, better management of existing woodlands and a renewed commitment to conserving and restoring ancient woodlands. It also requires that forests and woodlands should play a full part in achieving a resilient and coherent ecological network across England. The opportunity for England to contribute to the use of sustainably grown and harvested wood products is recognised, as is the nature of multifunctional forestry in order to support renewable energy and timber, new wildlife habitats and green space for people to use and enjoy, and mitigating and adapting to climate change. Forestry policy will also increase resilience to climate change, pests and diseases, and help to halt the loss of biodiversity.

1.5 Report structure

This report presents a climate change risk assessment (CCRA) for the forestry sector. The forestry sector covers trees, woodlands and forests in the UK and it embraces all their uses and benefits, including the timber production industry, their value as part of the natural environment and the recreation and amenity resource they provide. The report is structured into sections which include:

- scoping of impacts
- an assessment of the current policy context
- identification of the most important impacts (the 'Tier 2' impacts)
- identification of 'risk metrics', which are measures for the impacts of climate change
- development of response functions, which show how the metric values are affected by climate change variables
- calculation of the impacts of climate change for selected climate change scenarios
- evaluation of the impacts of climate change taking account future socio-economic change
- estimation of the costs of climate change
- discussion and conclusions.

The report structure broadly follows the risk assessment steps as described in detail in the CCRA Method Report (Defra, 2010). Additional information is contained in Appendices to this report.

2 Methods

2.1 Introduction: CCRA Framework

The overall aim of the CCRA is to inform UK adaptation policy, by assessing the main current and future risks (threats and opportunities) posed by the current climate and future climate change for the UK to the year 2100. The overall approach to the risk assessment and subsequent adaptation plan is based on the UK Climate Impacts Programme (UKCIP) Risk and Uncertainty Framework (UKCIP, 2003). The framework comprises eight stages as shown in Figure 2.1. The CCRA has undertaken the Stages 1, 2 and 3 as outlined below. Stages 4 and 5 will be addressed as part of a separate economic assessment, entitled the 'Economics of Climate Resilience', and the remaining stages will be implemented by the UK Government and Devolved Administrations. The framework presents a continual process that can adapt as new evidence and policy emerges; in the case of the CCRA the process will be revisited every five years.

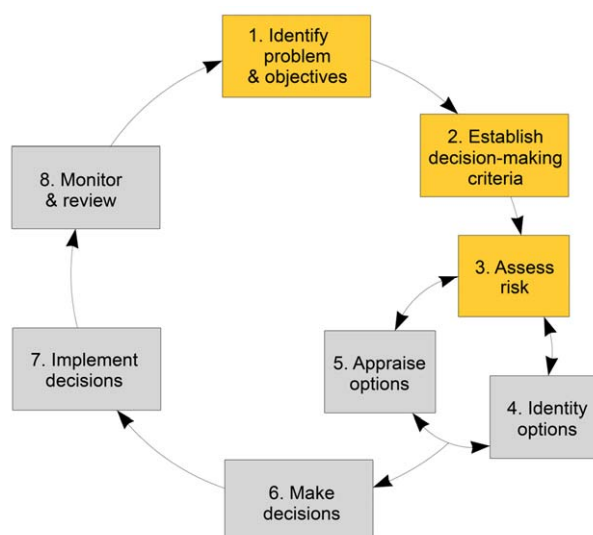


Figure 2.1 Stages of the CCRA (yellow) and other actions for Government (grey)

Adapted from UKCIP (2003).

- Stage 1 is defined by the aim of the CCRA project, to undertake an assessment of the main risks (including both threats and opportunities) posed by climate change that will have social, environmental and economic consequences for the UK.
- Stage 2 established decision-making criteria for the study, which were used to inform the selection of impacts for analysis in Stage 3. These criteria are the social, environmental and economic magnitude of consequences and the urgency of taking adaptation action for UK society as a whole.
- Stage 3 covers the risk assessment process. This involved a tiered assessment of risks with Tier 1 (broad level) identifying a broad range of potential impacts and Tier 2 (detailed level) providing a more detailed analysis including quantification and monetisation of some impacts. A list of climate change impacts was developed based on eleven sectors with further impacts added to cover cross-cutting issues and impacts which fell between sectors. This list of climate change impacts is referred to as the

‘Tier 1’ list of impacts. This list contained over 700 impacts – too many to analyse in detail as part of this first CCRA. A consolidated list of the highest priority climate change impacts for analysis was developed and referred to as the **‘Tier 2 list of impacts’**. This report presents the risk assessment for Tier 2 impacts.

The background to the framework and the approach used for each of the first three stages is set out in more detail in the CCRA Method Report (Defra, 2010). This chapter aims to summarise the CCRA method for the risk assessment stage (Stage 3 in the framework above) because this includes the specific steps for which results are presented in this report.

2.2 Outline of the method used to assess impacts, consequences and risks

The risk assessment presented in this report is the focus of Stage 3 in the CCRA Framework (see Figure 2.1). This was done through a series of steps as set out in Figure 2.2. These steps are explained in Sections 2.3 - 2.7 below and are discussed in more detail in the CCRA Method report (Defra, 2010).

The components of the assessment sought to:

- **Identify and characterise the impacts** of climate change
This was achieved by developing the Tier 1 list of impacts, which included impacts across 11 sectors as well as impacts not covered by the sectors and arising from cross-sector links (see Chapter 3 of this report).
- **Identify the main risks** for closer analysis
This involved the selection of Tier 2 impacts for further analysis from the long list of impacts in Tier 1. Higher priority impacts were selected by stakeholder groups based on the social, environmental and economic magnitude of impacts and the urgency of taking action (see Appendix 1 of this report and Section 2.5 below).
- **Assess current and future risk**, using climate projections and considering socio-economic factors
The risk assessment was done by developing ‘response functions’ that provide a relationship between changes in climate with specific consequences based on analysis of historic data, the use of models or expert elicitation. In some cases this was not possible, and a narrative approach was taken instead. The UKCP09 climate projections and other climate models were then applied to assess future risks. The potential impact of changes in future society and the economy was also considered to understand the combined effects for future scenarios (see Chapters 3 to 7 of this report and Section 2.6 below).
- **Assess vulnerability** of the UK as a whole
This involved:
 - i. a high level review of Government policy on climate change in the eleven sectors (see Chapter 1 of this report)
 - ii. a high level assessment of social vulnerability to the climate change impacts (see Appendix 2 of this report)

- iii. a high level assessment of the adaptive capacity of the sectors (see Chapter 8 of this report and Section 2.4 for an overview of the approach, below).

- **Report on risks** to inform action

This report presents the results of the risk assessment for the forestry sector. The results for the other 10 sectors are presented in similar reports and the CCRA Evidence Report (CCRA, 2012) draws together the main findings from the whole project, including consideration of cross-linkages, and outlines the risks to the UK as a whole.

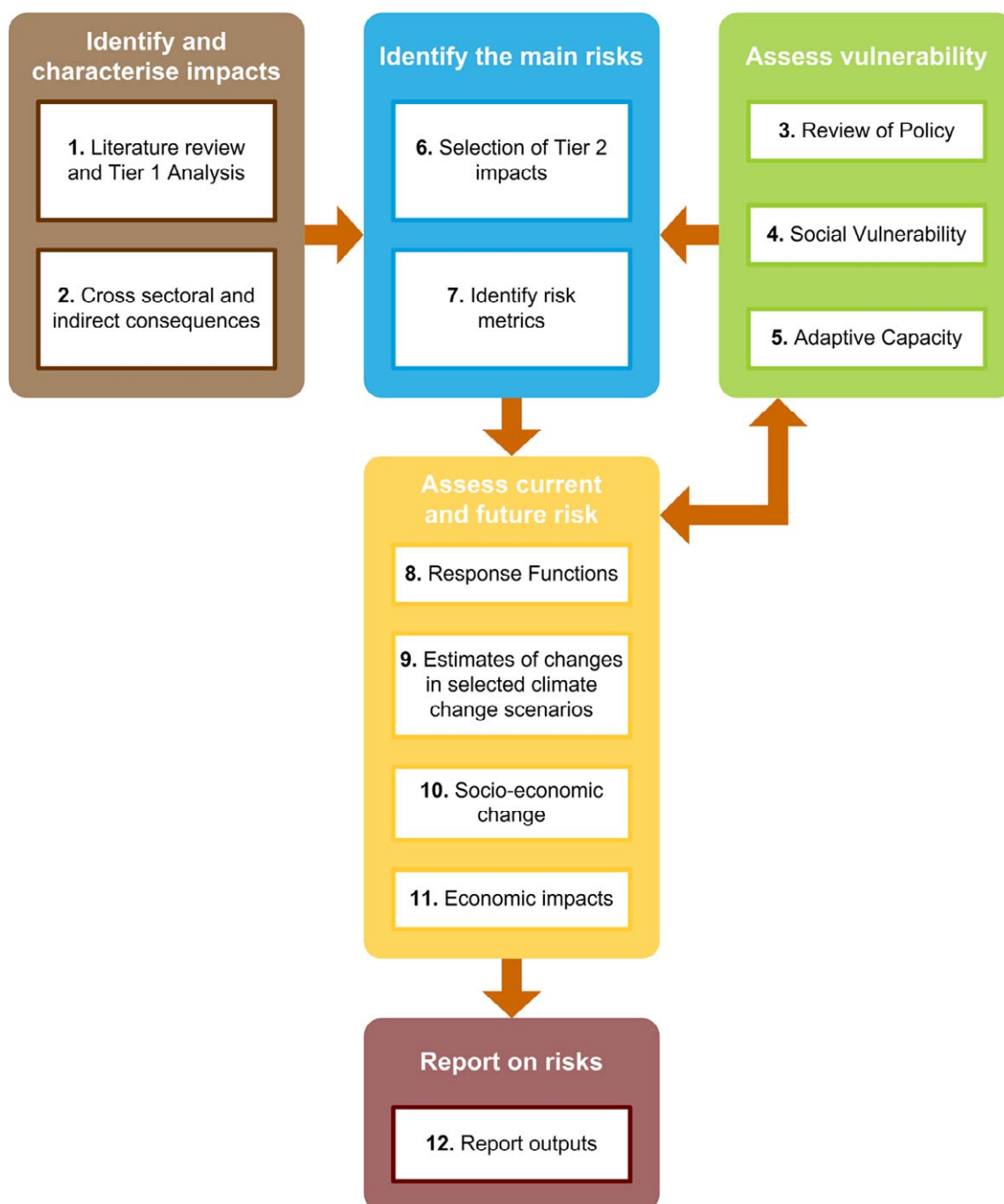


Figure 2.2 Steps of the CCRA method (that cover stage 3 of the CCRA framework: Assess risks)

2.3 Identify and characterise the impacts

Step 1 – Literature review and Tier 1 analysis

This step scoped the potential impacts of climate change on the UK based on existing evidence and collating the findings from literature reviews, stakeholder participation through workshops, correspondence with wider stakeholders and soliciting expert opinion. This work developed the Tier 1 list of impacts (see Appendix 1). The Tier 1 impacts have not been analysed in detail; high level discussion of these impacts is provided in Chapter 3 of this report.

Step 2 – Cross-sectoral and indirect impacts

The Tier 1 lists for the 11 sectors in CCRA were compared and developed further to include cross-sectoral and indirect impacts. This was done by 'Systematic Mapping', which sets out a flow chart to link causes and effects in a logical process. The impacts that were identified in this step were added to the Tier 1 list of impacts.

2.4 Assess vulnerability

Step 3 – Review of Policy

Government policy on climate change develops and changes rapidly to keep pace with emerging science and understanding of how to respond through mitigation and adaptation. This report includes an overview of selected relevant policy in Chapter 1 as this provides important context for understanding how risks that are influenced by climate relate to existing policies. This information will be expanded in the Economics of Climate Resilience project and the National Adaptation Programme.

Step 4 – Social Vulnerability

The vulnerability of different groups in society to the climate change risks for each sector was considered at a high level through a check list. The completed check list for the forestry sector is provided in Appendix 2. This information is provided for context; it is not a detailed assessment of social vulnerability to specific risks. Note that this step is different from Step 10, which considers how future changes in society may affect the risks.

Step 5 – Adaptive Capacity

The adaptive capacity of a sector is the ability of the sector as a whole, including the organisations involved in working in the sector, to devise and implement effective adaptation strategies in response to information about potential future climate impacts. A high level overview of the adaptive capacity of the forestry sector has been carried out through literature review and is presented in Chapter 8. This information is provided for context.

2.5 Identify the main risks

Step 6 – Selection of Tier 2 impacts

The Tier 1 list of impacts for each sector that resulted from Step 2 (see above) was consolidated to select the higher priority impacts for analysis in Tier 2. Firstly, similar or overlapping impacts were grouped where possible in a simple cluster analysis,

which is provided in Chapter 1. Secondly, the Tier 2 impacts were selected using a simple multi-criteria assessment based on the following criteria:

- the social, economic and environmental magnitude of impacts
- overall confidence in the available evidence
- the urgency with which adaptation decisions needs to be taken.

Each of these criteria were allocated a score of 1 (low), 2 (medium) or 3 (high) and the impacts with highest scores over all criteria were selected for Tier 2 analysis. The scoring for each sector was carried out based on expert judgement and feedback from expert consultation workshops (or telephone interviews). Checks were carried out to ensure that a consistent approach was taken across all the sectors. The results of the scoring process are provided in Appendix 1.

Step 7 – Identifying risk metrics

For each impact in the Tier 2 list, one or more risk metrics were identified. Risk metrics provide a measure of the consequences of climate change, related to specific climate variables or biophysical impacts. For example, one of the impacts identified was ‘effect of drought’ because of reduced precipitation. The risk metric that was identified to measure the consequences of this impact was derived from an understanding of how drought affects tree crown condition and tree growth. The risk metrics were developed to provide a spread of information about economic, environmental and social consequences. The metrics have been referenced using the sector acronym and a number; the forestry sector metrics are referenced as FO1 to FO4, but also include BD12 ‘Increased risk of wildfire’ from the biodiversity and ecosystem services sector analysis (Brown *et al.*, 2012) as a surrogate for forest fires.

2.6 Assess current and future risk

Step 8 – Response functions

This step established how each risk metric varied with one or more climate variables using available data or previous modelling work. This step was only possible where evidence existed to relate metrics to specific climate drivers, and has not been possible for all of the Tier 2 impacts. This step was carried out by developing a ‘response function’, which is a relationship to show how the risk metric varies with change in climate variables. Some of the response functions were qualitative, based on expert elicitation, whereas others were quantitative.

Step 9 – Estimates of changes in selected climate change scenarios

The response functions were used to assess the magnitude of consequences the UK could face from climate change by making use of the UKCP09 climate projections. This step used the response functions to provide estimates of future risk under three different emissions scenarios (high carbon emissions, A1FI; medium emissions, A1B; low emissions, B1²⁰), three future 30-year time periods (centred on the 2020s, 2050s and 2080s) and for three probability levels (10, 50 and 90 percent²¹), associated with single or combined climate variables. The probability levels are cumulative and denote the degree of confidence in the change given; for example 90% suggests that it is thought very unlikely that the change will be higher than this; 50% suggests that it is thought equally likely that the change will be higher or lower than this; and 10%

²⁰ see <http://ukclimateprojections.defra.gov.uk/content/view/1367/687/> for further details

²¹ see <http://ukclimateprojections.defra.gov.uk/content/view/1277/500/> for further details

suggests that it is thought very unlikely that the change will be lower than this. 90% does not mean that the change is 90% likely to occur, for example.

All of the changes given in the UKCP09 projections are from a 1961-1990 baseline.

For the tree productivity metric, FO4, the earlier UKCIP02 climate change projections were used, and thus do not have any probabilistic assessment. This is because modelling productivity requires multiple climate variables, which were not all available in the original UKCP09 resources. Work using UKCP09 scenarios for productivity projections is underway.

The purpose of this step is to provide the estimates for the level of future risk (threat or opportunity), as measured by each risk metric.

Step 10 – Socio-economic change

It is recognised that many of the risk metrics in the CCRA are influenced by a wide range of drivers, not just by climate change. The way in which the social and economic future of the UK develops will influence the risk metrics. Growth in population is one of the major drivers in influencing risk metrics and may result in much larger changes than if the present day population is assumed. For some of the sectors where this driver is particularly important, future projections for change in population have been considered to adjust the magnitude of the estimated risks derived in Step 9.

For all of the sectors, a broad consideration has been made of how different changes in our society and economy may influence future risks and opportunities. The dimensions of socio-economic change that were considered are:

- Population needs/demands (high/low)
- Global stability (high/low)
- Distribution of wealth (even/uneven)
- Consumer driven values and wealth (sustainable/unsustainable)
- Level of Government decision making (local/national)
- Land use change/management (high/low Government input).

The full details of these dimensions and the assessment of the influence they have on the forestry sector is provided in Chapter 6. Note that this step is different from Step 4, which considers how the risks may affect society; whereas this step considers how changes in society may affect the risks.

Step 11 – Economic impacts

Based on standard investment appraisal approaches (HM Treasury, 2003) and existing evidence, some of the risks were expressed as monetary values. This provides a broad estimate of the costs associated with the risks and is presented in Chapter 7 of this report. A more detailed analysis of the costs of climate change will be carried out in a study on the Economics of Climate Resilience²².

²² <http://www.defra.gov.uk/environment/climate/government/>

2.7 Report on risks

Step 12 – Report outputs

The main report outputs from the work carried out for the CCRA are:

- The eleven sector reports (this is the sector report for the forestry sector), which present the overview of impacts developed from Tier 1 and the detailed risk analysis carried out in Tier 2.
- The Evidence Report, which draws together the main findings from all the sectors into a smaller number of overarching themes.
- Reports for the Devolved Administrations for Scotland, Wales and Northern Ireland to provide conclusions that are relevant to their country.

3 Impacts and Risk Metrics

3.1 Introduction

Chapter 2 defines the process for identifying the Tier 1 and Tier 2 impacts. From a report scoping possible impacts of climate change to the forestry sector (Moffat and Morison, 2009), followed by consultation with experts across the sector (Appendix 1), a Tier 1 list of 30 impacts together with a pedigree rating and level of confidence (Table A1.1) and possible risk metrics (Table A1.2) was assembled. The list of the 30 impacts identified is shown in Table 3.1, with a brief commentary on each explaining why it was or was not taken forward to Tier 2.

Table 3.1 Main impacts, their climatic drivers and consequences for the forestry sector from the Tier 1 analysis. Those impacts taken forward for Tier 2 analysis are shaded.

Climate Effect	Impact	Consequence	Comment
1. Increased CO ₂ levels, longer growing season	Increase in productivity of some species e.g. for biomass production	Increased tree growth and potential supply of timber products, increased carbon sequestration.	Information is insufficient to quantitatively model for any other than very specific cases, so cannot be projected with confidence (see Section 3.2.11)
2. Increased CO ₂ concentration	Denser canopies	Reduction in light levels on forest floor and ground vegetation and community structure and species composition balance and functional types	There are many possible impacts of increased CO ₂ on woodland plants and other organisms, including differences in response between vegetation types and species. It is not clear that denser canopies would result. (see Section 3.2.11)
3. Drought / successive droughts	Serious damage to trees for example stem increment of beech; serious damage to tree stands	Reduced timber volume and high-quality timber supply; trees more susceptible to pests and pathogen; risk of tree mortality; effects on nutrient cycling, woodland wildlife and habitat types	Semi-quantitative understanding of these relationships for particular species only (see Section 3.2.2)
4. Drier summers (decrease in summer rainfall)	Oxidation of peatlands	Loss of forest soil carbon and effect on transmission of water through the catchment; possible exposure of acid sulphate soils	UK forestry policies constrain new woodland establishment on peatlands; limited area of forest on deep peatlands. (see Section 3.2.6)
5. Droughty conditions - increase in average temperature; wind	Increase in grass and forest fires / increased fire fighting	Mature tree damage; increased tree sensitivity to pest and pathogen; risk of soil erosion and water pollution; risk of destruction of wildlife habitat	Scientific understanding is evolving (see Section 3.2.9), also links to 8 below
6. Reduced snowfall	Decrease in snow damage (although the remaining snow may be 'wetter' and cause more damage)	Both positive and negative outcomes possible; interactions with pests and pathogens	Little quantitative evidence with which to establish consequence responses. See Section 3.2.7
7. Decrease in summer rainfall	Drought during period of woody growth	Reduced tree growth	Part of a continuum of effects of reduced water availability; see 3 above

Climate Effect	Impact	Consequence	Comment
8. Spring and summer drought	Newly planted trees threatened	Risk of significant increased tree mortality during 'establishment'; and also during regeneration	Additional costs to establish new and restock woodland. Possible need for irrigation in urban areas, and refinement of planting technologies. See Section 3.2.2 and links to 5 above
9. Increase in frequency of extreme rainfall events	Increase in localised flooding, channel scour, soil erosion and landslipping	Tree damage; disruption to local infrastructure, communities and businesses; risk of water pollution	Need for forest engineering to build climate projections into management systems for water in forests, e.g. redesign of roads, drains and culverts. Erosion and landslip considered in Section 3.2.10
10. Increased winter rainfall	Water tables raised enough to kill tree roots	Reduces effective rooting depth and makes trees more vulnerable to summer droughts	See Section 3.2.5
11. Increased winter rainfall	Waterlogging of soils	Reduce opportunities for machinery access to avoid damage to the soil; reductions in rooting depth reducing tree stability and making some species more vulnerable to summer drought. Reduced slope stability, enhanced landslip risk	See Section 3.2.5; in addition the window for forest thinning and harvesting operations may be affected, but difficult to assess as dependent on soil type, relief and drainage; more risk for short rotation forestry and short rotation coppice systems with more frequent machinery operations, although limited area. See Section 3.2.10 for slope stability discussion
12. Decrease in summer rainfall	Limits the current range of tree species that can be grown on droughty soils	Would affect species choice and thus many ecosystem goods and services including timber and woodfuel production, carbon sequestration	Impact would be reduced by appropriate choice of new species and varieties more tolerant of droughty conditions. See Section 3.2.2
13. Reduced soil moisture	Changes in species suitability	See above	See 12. above
14. Increased frequency of high or extreme temperature episodes / particularly droughts	Damaging effects of pests exacerbated	Tree damage and mortality; loss of timber quantity and quality	See Section 3.2.2
15. More extreme weather events	Migration of tree species/loss of native tree species in southern England	Biodiversity and habitat loss; possible threat to important woodland species	See Section 3.2.4
16. Changes in temperature, rainfall and frequency of extreme weather events	Biodiversity loss	Biodiversity and habitat loss; possible threat to important woodland species	See Section 3.2.4
17. More extreme weather events	Potential reduction in some of the damaging effects of pests	Reduced tree damage and yield losses (either quantity or quality)	See Sections 3.2.4; might be a benefit, although current understanding is that overall effect of extreme weather will be detrimental to forest ecosystems
18. Sea-level rise	Loss of habitat	Loss of woodland cover and ecosystem goods and services	Not considered further as very little woodland cover likely to be affected

Climate Effect	Impact	Consequence	Comment
19. Temperature / precipitation changes	Increase in 'weed' species	Rank vegetation that competes with young crop trees and non crop (native) species will result in greater mortality of young trees through aggressive competition	Not considered further as weed control is currently often necessary, and thus could be readily mitigated
20. Increase in average winter temperature	Winter chilling requirements for flowering or seed germination not met	Reduced or later flowering, seed set and thus natural regeneration; effects on food supply for other organisms	Qualitative and some quantitative data available; very species specific, so difficult to analyse generally. May be important in semi-natural woodland and that managed under LISS and CCF where regeneration key
21. Increase in average temperature (high temperatures)	Increase in emission of volatile organic compounds from trees	Interaction with other pollutant atmospheric gases and particulates; decline in air quality	See Read <i>et al.</i> (2009). Not taken forward because unlikely to be significant given low forest areas, except very locally
22. Higher earlier spring temperatures	Earlier budburst leading to increased damage by late frosts	Reduced high-quality timber supply because of loss of apical growth; crop damage, particularly to young trees.	A likely consequence given current understanding, though actual consequence for the sector unknown, see Section 3.2.7
23. Warmer winters (increase in average winter temperature)	Reduction in winter cold damage (although reduced hardening could reverse this benefit)	Possible benefits to tree survival and growth; depends on species and genotype	Partly considered in Section 3.2.7
24. Warmer winters (increase in average winter temperature)	Reduction in cold-associated mortality of insect pest, deer and squirrel populations	Increased tree damage and mortality; reduction in growth, loss of timber quantity and quality; loss of carbon sequestration	High likelihood of effect based on current understanding; see Sections 3.2.1 and 3.2.7
25. Warmer winters (increase in average winter temperature)	Potential for a range of new tree species	Maintenance of woodland cover, tree growth and delivery of ecosystem services	A good scientific understanding of possibilities; see Section 3.2.3
26. Increase in average winter temperature	Increase in delayed or incomplete winter hardening	Increased damage from autumn frosts and low temperature. More serious winter tree damage	Very species specific, while locally may be important, unlikely to be of national significance
27. Increase in average temperature; increased rainfall in spring and summer	Increase in pests and disease and activity	Tree damage and mortality; loss of timber quantity and quality; loss of carbon sequestration and other ecosystem services	A significant risk though prediction systems currently underdeveloped; see Section 3.2.1
28. Increase in storm events	Catastrophic wind throw	Reduced high-quality timber supply; loss of recreational areas; loss of habitat and other ecosystem services	A result of extreme climatic conditions, and difficult to model and predict; see Section 3.2.8
29. Change in storminess	Loss of mature woodland habitat	Damage as 28. above; some benefits associated with opening canopy enhancing regeneration	Of local importance, but wind throw unpredictable (see 28 above)
30. Lengthening growing season, wetter winter conditions	Possible reduction in the window for lifting nursery stock	Theoretical possibility constraining forest nursery trade	Unlikely to be significant because of well drained nature of nursery soils; may be more of a problem in planting opportunities (see related 11 above)

Climate Effect	Impact	Consequence	Comment
new. Increased temperatures and CO ₂ levels and changed levels of precipitation	Changes in soil organic carbon	Implications for forest ecosystem	See Section 3.2.6
new. Increased temperatures and humidity and precipitation levels	Increase in invasive flora and fauna	Threat to native habitats and woodlands	Potential impact on native UK species
new. Increased summer temperatures	Changes in lifestyle patterns and the natural environment affecting tourism visits and movements	Opportunities for forestry	Although tourism numbers are likely to increase, very difficult to estimate

Note that for some of the climate drivers opposite effects are considered (e.g. 12 and 27); this is because the uncertainty in climate projections, particularly for variables like rainfall, is such that there is a probability of decreases as well as increases.

The Tier 1 list was classified into four main overlapping clusters or themes (Figure 3.1):

- *Woodland habitats*: change in climate may influence the habitats and biodiversity of forest ecosystems.
- *Timber supply*: climate change and extreme weather events can cause damage to timber stocks and also provide opportunities for the forestry sector.
- *Industry practices*: changes to the growing season and climate related pressures influence the activities of foresters.
- *Recreation and local community*: potential climate change impacts such as forest fires, erosion, water logging and tree species change can influence the quality and availability of the forest resource for amenity use by people.

The analysis of the themes grouped together some of the impacts so that the initial list of 30 impacts was rationalised to 16; each one of these 16 impacts is shown in Figure 3.1, with reference to the numbering of impacts in the Tier 1 list provided in Table 3.1. Three additional impacts were added to this list of 16 at the Tier 2 stage, including one from the systematic mapping (sys.map.) exercise (CCRA, 2011).

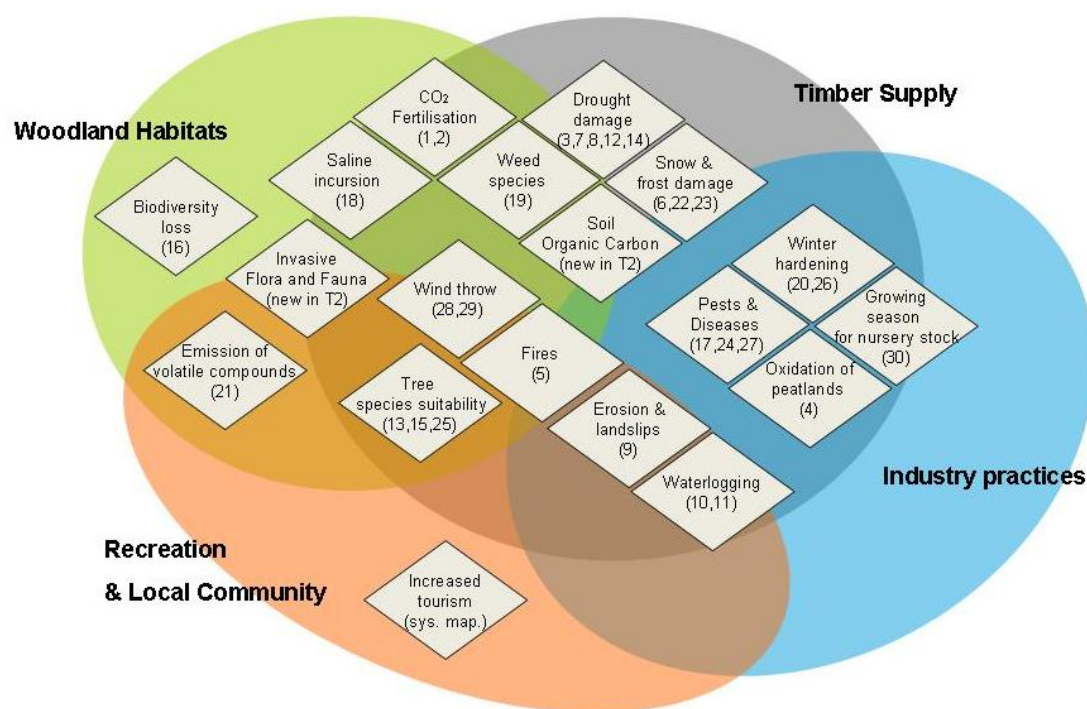


Figure 3.1 Clustering of Tier 1 impacts into four sector ‘themes’

A simple selection process was carried out to identify from the 30 impacts, those for further assessment in the Tier 2 risk assessment. The criteria agreed by the technical advisory group to the CCRA (the In-House Experts Group) used to prioritise the consequences were:

- Magnitude of consequences:
 - Economic
 - Social
 - Environmental
- Likelihood of the consequence occurring
- Urgency with which a decision needs to be made.

The criteria were equally weighted and the scores were derived according to standard descriptions in the CCRA method report (Defra, 2010). The scoring is primarily based on qualitative information and attempts to record ‘orders of magnitude’ rather than offering unfounded precision. The scoring is similar to the Cabinet Office’s National Risk Assessment, although at a higher level, given the wide ranging uncertainties in the climate change impacts assessment, and with an equal emphasis on environmental impacts. Scores are derived from the following equation:

$$100 * \left(\frac{\text{Social} + \text{Environmental} + \text{Economic}}{9} \right) \left(\frac{\text{Likelihood}}{3} \right) \left(\frac{\text{Urgency}}{3} \right)$$

The scores for each impact are given in Table A1.3 and a summary is presented in Table 3.2. Scores were allocated in line with the high/medium/low category descriptions provided in the CCRA method report (Defra, 2010) for each scored element. Evidence and justification for the scoring was from a variety of published research sources and expert judgement from the sector champion and colleagues in Forest Research.

The list of scored impacts for the forestry sector was assessed in comparison to the scores for impacts in all other sectors to identify a threshold score for selecting impacts for the Tier 2 analysis and ensuring consistency in the scoring and selection of impacts between sectors.

The selected impacts for the Tier 2 analysis are highlighted in Table 3.2; because of the clustering shown in Figure 3.1 they include 12 of the original Tier 1 impacts listed (numbers shown in parentheses). They are the impacts for forestry of climate change on:

- Pests and pathogens.
- Drought effects (in terms of drought damage and/or loss of productivity).
- Tree species change. In applying the risk assessment method, the analysis has focused on the impact on the commercial suitability of tree species.
- Woodland biodiversity.

Table 3.2 Summary Impact Scores. * Magnitude score listed is the highest of the three scores for the economic, environment and social elements

Name of 'rationalised' consequences (incl. individual impact reference numbers from sectors summary report)	Magnitude*	Likelihood	Urgency	Tier 2 impact?
Pests and diseases (17, 24, 27)	High	High	High	Yes
Drought damage / loss of productivity (3, 7, 8, 12, 14)	High	Medium	High	Yes
Change in tree species suitability (13, 15, 25)	High	High	High	Yes
Biodiversity loss (16)	High	High	High	Yes
Waterlogging (10, 11)	Medium	Medium	High	Possible
Change in soil organic carbon	High	Medium	High	Possible
Snow and frost damage (6, 22, 23)	Low	High	High	Possible
Wind throw (28, 29)	High	Low	High	Possible
Fires (5)	Medium	Medium	Medium	Possible
Erosion and landslips (9)	Low	Medium	High	
CO ₂ fertilisation (1, 2)	Low	High	Low	
Saline incursion (18)	Low	High	Low	
Emission of volatile compounds (21)	Medium	Medium	Low	
Winter hardening (20, 26)	Medium	Medium	Low	
Oxidation of peatlands (4)	Low	Medium	Low	
Weed species (19)	Low	Medium	Low	
Invasive flora and fauna	Low	Medium	Low	
Increased tourism	Low	Low	Low	
Growing season for nursery stock (30)	Low	Low	Low	

The Tier 2 impacts are assessed through 'risk metrics', which aim to provide a measure of the risk associated with each selected impact. Although forest biodiversity loss was identified as an important impact to consider further, it was not possible to devise a suitable metric and response function to characterise this. The risk metrics that were selected are:

- FO1 Forest extent affected by pests and pathogens
- FO2 Loss of productivity due to drought

- FO4 Change in tree species suitability and productivity
- BD12 Increased risk of wildfire.

Full details on the analysis of these metrics are provided in Chapter 4 of this report.

3.2 Main forestry sector impacts

The following section provides a brief scientific assessment of the nature and degree of the impacts likely to affect the forestry sector, covering the eleven highest scoring in Table 3.1. In addition to the four impacts that were selected for the forestry sector Tier 2 analysis (in blue), five additional impacts (in yellow) also scored highly and were considered possible candidates for further analysis if resources permitted. The impacts of 'erosion and landslips' and 'CO₂ fertilisation' are also considered important and are included in this section.

3.2.1 Pests and pathogens

Insect pests and microbial pathogens already have significant impacts on certain forests in the UK, and thus affect a range of goods and services. Whilst there is little evidence to date that the prevalence and severity of outbreaks of existing pests and pathogens in the UK have been directly impacted by climate change (Broadmeadow *et al.*, 2009a), there is increasing global understanding of the role of climate, and climate change, in affecting certain tree pest and pathogen activities and effects (e.g. Logan *et al.*, 2003; Woods *et al.*, 2005; Desprez-Loustau *et al.*, 2007; Fabre *et al.*, 2011; Sturrock *et al.*, 2011). Changes to temperature and relative humidity in particular can be expected to directly affect pest and pathogen biology, and extreme weather conditions may also exacerbate the damaging effects of some of these pests and pathogens. The majority of insect pests that currently affect UK forestry are likely to benefit from climate change as a result of increased activity and reduced winter mortality (Straw, 1995). However, other effects may be indirect. For example, drought can cause stress to trees, which may then be more susceptible to pathogens and insect pests, such as bark beetles and defoliators (Wainhouse, 2005), or storm damage may create wounds for entry by pathogens. Further discussion of the possible interactions between climate change and pest and pathogen impacts is given by Broadmeadow *et al.* (2009b).

Forest condition, as evaluated from the crown density of forest trees, varies from year to year largely dependent on the severity of pest and pathogen outbreaks and is therefore weather mediated. Forest monitoring from 1987 to 2004 has shown that there was little scientific evidence of widespread and persistent forest decline in any of the main commercial species, except possibly in oak (Hendry *et al.*, 2005). Nevertheless, in more recent years, a range of damaging agents has been found to affect some important tree species²³. For example, widespread failure of Corsican pine (*Pinus nigra* ssp. *laricio*) is occurring across its distribution in England, Wales and Scotland, because of the devastating effects of Red Band Needle Blight (RBNB) caused by the fungus *Dothistroma septosporum*. Reasons for the increase in disease incidence are unclear but it could be caused by increased rainfall in spring and summer coupled with a trend towards warmer springs, optimising conditions for spore dispersal and infection (Brown and Webber, 2008). RBNB is becoming more apparent on other

²³ <http://www.forestry.gov.uk/forestry/infd-6abl5v>

pine species including lodgepole pine (*Pinus contorta*) and Scots pine (*Pinus sylvestris*)²⁴.

Similarly, *Phytophthora ramorum* is a fungus-like pathogen of plants that is now causing extensive damage and mortality to trees and other plants across the United Kingdom. It has also been found in a number of European countries, but mostly on plants and shrubs, especially *Rhododendron*, *Viburnum* and *Camellia*, and has caused significant damage and mortality to many trees and other plants in parts of the USA. However, few trees in the UK were affected until 2009, when *P. ramorum* was found infecting and killing large numbers of Japanese larch trees in south-west England. Since then disease outbreaks have spread to other parts of England, Wales, Scotland, Northern Ireland and the Republic of Ireland. Studies into the sensitivity of *P. ramorum* to climate variables, specifically, temperature, humidity and water potential have identified optimal levels for growth at different stages of the organism's life cycle (Defra, 2004, 2007, Tooley *et al.*, 2009). Work has also identified the impact of extremes in temperature and moisture (Defra, 2004, 2007) and recovery ability from those extremes (Tooley *et al.*, 2008). Collectively, these studies suggest that the UK is currently a very suitable area, climatically, for *P. ramorum* survival. In the USA, Venette (2009) has undertaken a preliminary assessment of the possible effects of climate change on *P. ramorum* pathogenicity, but predictions in the UK have yet to be undertaken and are arduous and uncertain given the complexity of its biology and lifecycle.

Large-scale damage and induced premature mortality caused by pests and pathogens will have a significant effect on all parts of the chain of timber supply and on the timber processing industry. For example, RBNB is already affecting forest nursery suppliers who have had to adjust to a Forestry Commission embargo on Corsican pine planting on the public forest estate, and consequent larger demand for other tree species. In addition, quarantine controls apply to tree nurseries which require RBNB infected stock to be destroyed. Other pine species at the same nursery may not to be moved until they have been found to be free of infection for one full growing cycle, which may be up to two years following first detection. Secondly, the market for infected trees is reduced, with possible opportunities to support firewood supply businesses only. Loss of revenue for growers is inevitable, given that most of the timber was expected to support more profitable outlets such as construction. Sawmills and other processors may be affected by the downturn in timber supplies. Indeed, the investment in these processing plants is very dependent upon a good understanding of supplies over decades rather than years, so significant uncertainty can result in plant closure and relocation. Widespread forest deterioration caused by pest and pathogen outbreaks may also affect recreation and tourism.

3.2.2 Drought

Summers that are particularly dry can cause serious and widespread drought damage to trees and forest stands in the UK (Green and Ray, 2009). Drought damage may be observed as tree dieback or death. Drought probability depends not only on rainfall amount and seasonality, but also on soil type and depth which determines water holding capacity, and on tree species as they can differ in the threshold or range of soil water deficits that cause damage. Thus the assessment of drought risk is complex and needs to consider local differences; the impact is greatest and most noticeable on tree species that are not well matched to local site conditions (Read *et al.*, 2009). Drought, experienced as an extreme soil moisture deficit, can cause the xylem of trees to collapse, leading to stem lesions, and cracks through the cambium (Green and Ray, 2009). Stem cracking, called 'shake', that results from drought in spruce and fir

²⁴ <http://www.forestry.gov.uk/forestry/INFD-74JJFK>

species, makes timber unsuitable for structural use and therefore dramatically reduces its value. Recent drought years have induced visible and well known effects on tree crown colour and defoliation, and probably contributed to the view from many Tier 1 consultees (Appendix 1) that drought was likely to become a serious impact in future years.

Drought also makes trees more susceptible to a number of fungal diseases including the root diseases *Armillaria* spp. and *Heterobasidion annosum*, and to insect attack, especially from bark beetles which themselves can introduce disease (Green *et al.*, 2008). Drought damage leading to dieback has been observed in a range of species in the UK, including oak, ash and beech, and is associated with 'top dying' in Norway spruce.

However, it is important to note that tree growth reductions and yield losses can occur at soil water contents above those associated with drought and visible damage (Pereira *et al.*, 2006). Therefore, in parts of the UK projected to have more frequent summers with larger soil moisture deficit, especially areas in the east of England and Scotland (see e.g. Broadmeadow *et al.*, 2009b) there would be significant reductions in growth and yield of some of the major commercial production species (Broadmeadow, 2002), and there may be increased incidence of drought damage.

3.2.3 Tree species suitability

Climate projections indicate higher seasonal temperatures and a longer growing season resulting in an increase of accumulated temperature (an index of warmth) of between 40 and 60% for large parts of the UK by the 2080s (Broadmeadow *et al.*, 2009b). At the same time, soil moisture deficit (an index of "droughtiness") is likely to increase by between 40 and 50% in the same areas. Other areas, especially at higher elevations and in the west of Wales and Scotland, are expected to become wetter. These changes in climate would have substantial impacts on tree species suitability in terms of growth and survival, and it is therefore necessary that the suitability of commercially grown species for future local climates is reconsidered.

The ESC (Ecological Site Classification) forestry decision support tool uses biophysical factors including accumulated temperature and moisture deficit to provide current and projected species suitability. Using this tool, the area suitable for five major forest species considered by Read *et al.* (2009) is expected to decline in projected 2050s and 2080s climates in east and west England. This change in suitability would be expected to be seen as reduced productivity of commercial forests in these areas. Conversely, in Scotland and Wales the major commercial species, Sitka spruce, is projected to have an increased area that is classed as very suitable (Read *et al.*, 2009). Sitka spruce in Scotland may be expected to have increased productivity of 2 – 4 m³ ha⁻¹ where nutrients are not limiting (Ray, 2008a). Detailed analyses of species suitability changes based on ESC have been published for England, Scotland and Wales (Ray, 2008a; Ray, 2008b; Ray *et al.*, 2010).

It is worth noting that these previous calculations of changes in species suitability were based on changes to the mean climate and did not take into account variability; although work is now underway using the UKCP09 projections. In addition the ESC tool does not take into account extremes such as wind storms and unseasonal frost, and these additional risks should be considered separately. However, the ESC approach provides the basis for species choice adaptation to climate change that could provide substantial benefits for forest productivity in some areas, and an improved resilience to a range of risks through species diversification (Ray, 2008b). Increases in productivity will be beneficial across the forestry sector as a whole, and will also support its contribution to carbon sequestration services.

3.2.4 Biodiversity

Conservation of biodiversity is an essential part of sustainable forest management in the UK (Forestry Commission, 2004). Forests and woodlands provide habitats for a large array of plants and animals, some of which are rare or threatened. The UN Convention on Biological Diversity links directly to initiatives at UK and country level on Biodiversity Action Plans. The UK Biodiversity Action Plan (UKBAP) lists 65 priority habitats, of which nine are classified as woodland. The UKBAP also lists 1149 priority species and between 470 and 490 of these are either dependent upon or associated with woodland – more than those listed for any other terrestrial habitat. A significant proportion of woodland and associated habitats is designated or has other legal protection. The UK National Ecosystem Assessment clearly recognises the importance of woodland and forest biodiversity (Quine *et al.*, 2011).

Concerns over the integrity and future character of forest biodiversity in the face of climate change were raised consistently during the consultation around Tier 1 results (Appendix 1). Such concerns were generated in part as a result of the need or desire to conserve important woodland wildlife habitats as they are currently classified and managed (i.e. to preserve priority and/or important woodland habitat where it currently occurs). Other interests sitting within the broad concept of biodiversity include the conservation of particular species of woodland fauna and flora, notably those considered rare or endangered. Another point of view focused on the preservation of diversity itself. Because biodiversity is such a complex and, in many respects, a personal and political concept (Escobar, 1998), and because individual species respond to climate in individual ways, it was not possible to develop a single response function by which to explore the possible changes caused by climate change. Nevertheless, there has been much work to explore likely effects on woodland biodiversity, and UK evidence of climate change impact on habitat and species is considerable. A number of comprehensive reviews have been produced summarising effects across different taxonomic groups, biological systems, regions and types of response (e.g. Parmesan and Yohe, 2003; Root *et al.*, 2003; Hickling *et al.*, 2006; Thomas *et al.*, 2006; Berry *et al.*, 2011).

Changes in climate can affect a species' autoecology including phenology, growth, reproduction, germination, establishment, competition and response to herbivory (Fitter and Fitter, 2002; Sparks *et al.*, 2002). These impacts not only affect species and their populations, but can have major implications for community structures and ultimately even ecosystem function (McCarty, 2001).

Berry *et al.* (2011) have recently reviewed how climate change might affect woodland biodiversity and community functioning, and Box 3.1 summarises important findings relating to individual woodland species and priority habitats. However, Berry *et al.* (2011) concluded that predicting changes with confidence is difficult because bioclimatic models do not take biotic interactions into account, which are very important determinants of species success and community structure at a small scale. Nevertheless, they considered that the major structural elements of UK woodlands will, or can, be maintained. Changes to ecosystem function are even harder to predict, but while many functions could be maintained, some, on which specialist species rely such as specific decomposition pathways, could be more affected.

Box 3.1 Effect of climate change on woodland species and priority habitats - analysis based on bioclimatic modelling (from Berry *et al.*, 2011)

From 178 woodland-related species for which modelling results were available, some may be 'winners', but a considerable number may lose potential bioclimatic space in the British Isles in the forthcoming decades. These include, for example, pied flycatcher, twinflower and narrow-headed ant. South-east England would potentially be hit hardest by species losses, with many species, including major canopy trees, losing bioclimate space from 2050. Many species that are dominant in the south today, however, may be more successful competitors in the north in the future. Some mobile species gain bioclimatic space, including charismatic species such as dormouse. However, a number of species with strongholds in Scotland because of present cooler conditions are likely to suffer including Scottish crossbill, Scottish wood ant and capercaillie.

On the basis of modelling of the impacts of climate change on a range of species associated with woodland priority habitats, it is likely that Wood Pasture and Parkland habitats, Upland Oakwoods and Upland Mixed Ashwoods will see few changes. Lowland beech and Yew woodland could extend into northern Britain, but may suffer losses, as although beech is projected to have suitable future climate space, in reality, its intolerance to drought may reduce its growth and competitiveness, especially in south-east England. This may result in shifts to more oak dominated woodlands. Yew woods should remain fairly resistant to climate change. The species found in Wet Woodland have a mixed response in the modelling results, as both willow species suffer bioclimate space losses, although alder, a major component of many wet woodlands gains slightly. Lowland Mixed Deciduous Woodland should remain relatively stable. A number of important tree species could experience small losses which may affect the competitive balance in some woodlands (e.g., between ash and oak in ash woodlands) although there are some striking gains including three rare species (large-leaf lime and both service trees). Upland Birchwoods and Scots pine woodlands are possibly the major losers in this study. Both the iconic species in Upland Birchwoods (silver and downy birch) lose bioclimate space as well as the other major trees (rowan, grey willow and wych elm). The two winners are both oak species which suggests that even on the less stable soils and in canopy gaps, the birches may not be successful colonisers and oak may dominate. For Scots Pine Woodland, Scots pine is projected to lose significant amounts of climate space under the high emission scenario by 2080, although it is unlikely that this will lead to immediate range reduction because of the species' longevity. Pests and diseases of Scots pine are, however, likely to increase with higher temperatures, but incidents of fire may increase, which often aid the regeneration of Scots pine and silver birch. Woodland structure, therefore, may change, with sessile oak stands possibly increasing, while Scots pine decreases, and subsequently, the species associated with Scots pine could also decrease, including Scottish crossbills and wood ants.

3.2.5 Waterlogging

Increased rainfall alone would not necessarily increase the occurrence of waterlogging, which depends on the balance between rainfall, evaporation, drainage and runoff. Waterlogging risk therefore depends on climatic, vegetation, landscape, management and soil type factors, and would require spatially detailed analysis to consider changes with climate change. Upland forests in the UK, which include most of the commercial productive conifer plantations, have soils that are predominantly not free draining. For the UK as a whole, 33% of the forest area is on soil types that have high organic material (peaty gleys or podzols and deep peats). Surface water gleys cover an

additional 15% of the forest area. All these soil types commonly have water tables that fluctuate throughout the year and may be close to the surface for parts of the year, usually the winter months. If rainfall increases, these seasonally fluctuating water tables will approach closer to the surface, and for longer periods. For this reason, woodland creation on soils prone to waterlogging usually relies on some form of artificial drainage. Clearly, an adaptation response to increased waterlogging could be increased use of drainage or altering drainage practice (deeper, closer drains etc.), although there are costs of doing this, and it has implications for the necessary infrastructure within forests (such as culverts) and for landscape scale hydrological responses. Use of increased drainage may also have implications for soil carbon stocks, if it causes drier soil conditions in summer, and thus more decomposition.

The anaerobic conditions in waterlogged soils do not permit growth of roots of most tree species, and the active parts of roots that have grown in soil that becomes waterlogged will die. However, roots of some conifer species have been found to tolerate waterlogging if they are fully dormant in the winter. Tree species that can tolerate waterlogged soils when active include willows and alders. Lodgepole pine can also grow deeper into waterlogged soil than most other conifers and has been used to help dry out wet sites to make them suitable for other species.

Root death or dieback resulting from waterlogging reduces or limits the rooting depth of trees. As rooting depth is closely related to the anchorage strength of root systems, trees that have limited rooting depth on waterlogged soils will be less wind-stable than trees on free draining soils, and therefore have an increased risk of wind damage (see Section 3.2.8). Where roots are killed by a rising water table, the soil will lose the cohesion benefit of the roots. This loss, in combination with the reduced strength of saturated soil, will make waterlogged forest soils considerably more prone to erosion and landslides. While increased waterlogging will, in the short and medium term, reduce soil organic carbon loss because of reduced decomposition, the reduction in root growth and in soil faunal and microflora activity will over the long-term lead to a reduction in organic matter incorporation at depth, affecting soil structure.

An additional risk to trees from rooting depth that is limited by seasonally high water tables is that on sites that dry out in summer months, roots may be unable to reach available water for parts of the growing season, leading to increased water stress, reductions in shoot growth and in severe cases may lead to increased mortality (see Section 3.2.2 above). In addition, waterlogging and the consequent anaerobiosis is implicated in the spread and attack of some important root pathogens (e.g. *Phytophthora*).

3.2.6 Change in soil organic carbon

Temperate forest soils usually contain considerably more organic carbon (SOC) than is contained in the woody biomass of the trees, and this is a major ecosystem service that UK forests provide, as well as a key factor affecting soil properties and function. Across the UK forest area, 75% of the organic carbon stock is held in the soils (down to 1 m depth), and the proportion is higher in Scotland (81%) because of the large area of peat soils (Read *et al.*, 2009, Morison *et al.*, 2011). Mineral soil types (such as brown earths and podzols) have mean total carbon stocks of 133-155 tonnes of carbon per ha⁻¹ down to 80 cm, (Read *et al.*, 2009). Deep peat soils have a three-fold larger carbon stock down to 80 cm, and as they may be up to 6 m deep (Smith *et al.*, 2007, 2009) they can contain very large carbon stocks, although only 7% of UK forest area is on deep peat soils (Morison *et al.*, 2011). In general, UK peatlands are considered at substantial risk from climate change, because of both loss of the climate conditions suitable for new peat formation in some areas, and also because of possible increased loss of existing peat stocks (Natural England, 2010).

Climate change (particularly temperature, solar radiation and rainfall) may affect SOC content directly through changing decomposition rates and through affecting organic carbon inputs from litter formation, root death and rhizodeposition. Broadly, higher temperatures in the cool temperate climate of the UK would increase soil decomposition rates, resulting in loss of SOC stocks, although this may be offset by increased plant growth and consequent higher inputs. Warmer conditions would extend the growing season length and the period of more active soil decomposition, and the effect may be relatively large in the cooler upland areas of the UK. However, higher temperatures are likely to increase evaporation, resulting in drier soils, and therefore reduced decomposition rates, particularly during summer. On the multi-annual timescale of tree growth it is also important to understand the interaction between SOC turnover, nutrient cycling and tree growth. Thus warmer conditions are likely to result in increased decomposition and loss of SOC, but increased inorganic nitrogen availability and increased tree growth, as demonstrated experimentally by a seven year study in a deciduous forest in New England (Melillo *et al.*, 2011).

The impacts of precipitation changes are less easy to generalise, as they will depend on existing regimes. In already wet areas, increased rainfall may lead to waterlogging, which may result in reduced decomposition (see Section 3.2.5 above); conversely drier conditions would lower water tables increasing decomposition and consequent CO₂ loss (although decreasing methane emissions). In dry areas, reduced rainfall may lead to reductions in decomposition, particularly during summer. Prolonged drought may cause or exacerbate peat cracking in organic soils and thus increased drainage and SOC loss. Increased frequency of high rainfall events may also cause more runoff or particulate organic carbon (POC) and dissolved organic carbon (DOC). Increased rainfall may also cause more leaching of nutrients, reducing tree growth.

If the frequency of very dry spring and summer conditions increases, then this may cause increased wildfire occurrence (see Section 3.2.9 below). Depending on the severity of the burn, fires may cause substantial losses in SOC, both by direct combustion, and by subsequent POC losses from denuded woodland areas, and increased DOC losses because of increased throughflow following peat cracking (Smith *et al.*, 2007).

There will also be indirect effects of climate through changes of tree and other vegetation species, changes to tree health and mortality through pests and disease changes, and through management changes, such as silvicultural practices, wood end use or species choice and rotation length. It is well understood that forest management has a major impact on SOC, in particular through major changes initiated during woodland creation from other land uses, or during woodland removal. Thus it can be argued that the indirect effects of management will be more significant than the changes of climatic variables. The recent ECOSSE reports (Smith *et al.*, 2007, 2009) concluded that SOC stocks of peat soils in Scotland will decline slightly over the next 50 years because of climate change, but that the changes will be much less than those likely from land use change. However, their analysis was not able to take into account changes in vegetation composition driven by climate change which will also alter peat formation and peatland protection (Morison *et al.*, 2010).

3.2.7 Snow and frost damage

The number of days with air frosts (air temperature <0°C) has decreased sharply during the past four decades, with an average reduction of approximately 20 frost days per year over much of the UK between 1961/62 and 2006/7 (Jenkins *et al.*, 2009). In colder upland regions the declines in frequency have been larger, up to 30 days. Most frost days occur in winter, and thus most of the change has been during the three winter months (D, J, F). Declines in spring (M, A, M) have been between 4 and 6 days

in the different UK regions, and in autumn only 2 to 5 days. Clearly, as temperatures are projected to increase, this reduction in frost frequency will probably continue. In general this will be beneficial to tree growth, as it is a component of the warming trend, and contributes to the increasing length of the growing season. However, the much colder conditions in the last two winters (2009/10 and 2010/11) have gone against the above trend; for example, the number of air frost days in December 2010 was the highest for 50 years (UK Met Office records). In addition, very low temperatures occurred which has led to substantial mortality of sensitive tree species in several locations across the UK. Eucalypts of several species were particularly affected. This illustrates both the damage that can occur from extreme events and that the risk of a range of temperature minima needs to be assessed, not just occurrence of air frost.

Even without such extreme winter cold spells, the risk of frost damage may remain for several reasons. Firstly, longer growing seasons may result in later onset of dormancy and or less winter hardening for trees, leaving shoots more prone to early autumn frost and winter cold damage. This is particularly the case if longer growing seasons have promoted the growth of lammas shoots (shoots growing beyond the terminal bud set at the end of the main part of the growing season). Tender shoots formed in this way are especially vulnerable to early autumn frost, which could lead to stem forking. Additionally, the lammas apical shoots set a second whorl on the stem leading to increased knottiness in sawn timber (Ray *et al.*, 2008). The effect of this will depend on both species and provenance, as there is substantial variation in phenology (timing of growth phases). However, for the main conifer species day length is the critical factor leading to trees beginning to enter dormancy, which is therefore uncoupled from temperature change.

Secondly, warmer springs lead to earlier bud break in many temperate tree species which are not strongly controlled by day length. This can increase the risk of damage to new leaves from late spring frosts. The trend of earlier bud-break of many tree species is well documented in the UK; for example, there has been an advance of leafing date in oak by about three weeks on average since the 1950s (Sparks and Gill, 2002; Broadmeadow *et al.*, 2009a). However, there has been no similar clear change in the date of the occurrence of the last spring frost, so that risk of damage has actually increased. Not all tree species respond to warmer springs in the same way, as some require more winter chilling to prime them before subsequent bud break when temperatures rise in the spring, and therefore leafing may be delayed by warmer winters (Murray *et al.*, 1989), reducing frost damage risk in these species.

Other impacts of reduced frost frequency (and more generally less cold winter temperatures) will be through reduced winter mortality of insect pests such as aphids, and possibly vertebrate pests, such as squirrels and deer.

Heavy snowfalls can cause damage to trees, by breaking branches, and this damage is typically confined to evergreen, predominately conifer species, as deciduous species are usually leafless when snowfalls occur. Most conifer growth habits are such as to reduce snow loading, but significant damage can occur, particularly to young trees. Snow conditions can cause more grazing damage to trees from deer as normal food sources are harder to find. Increasing air temperatures are likely to reduce the incidence of snow, in general, which will be a benefit, although it will depend on storm tracks and the frequency of occurrence of the particular conditions that combine precipitation and cold temperatures. However, as the climate projections currently indicate an increase in winter rainfall it may be that at higher elevations where there is more likelihood of being above the freezing level, there would be larger snowfalls. In addition, it may also be 'wetter' snow and thus heavier, leading to more damage.

3.2.8 Wind throw

The UK has one of the windiest climates in Europe and its forests are therefore particularly vulnerable to damage from high winds. Wind throw in the UK usually occurs during severe north Atlantic depressions, and therefore is most common in winter months, which is also when soils are wettest. Statistically, wind throw is the largest cause of damage to forests (abiotic or biotic) in the UK (Forestry Commission, 2011b), and most significant across Europe after damage from pests and pathogens (Forest Europe, UNECE and FAO, 2011). Wind throw damage may occur as either uprooting of trees or snapping of stems (Quine *et al.*, 1995). Although timber can be salvaged from wind thrown trees, the cost is considerably greater than normal harvesting, and the value of the timber will be reduced especially if stems have snapped or are subsequently damaged by fungal infections such as 'blue stain'. Wind throw areas make the forest more vulnerable to pests such as bark beetles. Severe wind throw can cause disruption to forest management and activity, can damage or disrupt infrastructure such as roads and power supplies, increase soil erosion, and with large amounts of timber suddenly available, has the potential to depress timber prices across the UK.

The risk of wind throw is often currently considered in forest management decisions such as timing of thinning and harvesting, and a decision support system (ForestGALES) (Gardiner *et al.*, 2006) is available to forest managers to help them consider wind risk implications of their decisions. In the UK, forest stands in the windiest locations and on soils with shallow rooting are left unthinned to reduce the risk of wind throw, and the age at which they are harvested is limited by the increasing wind risk as trees grow in height.

The area of forest vulnerable to wind throw has increased in the UK as the forest estate has matured over the last century (Figure 1.2). Similarly across Europe, wind damage to forests has increased greatly as the standing volume has increased. Wind throw risk may change as a result of climate change where rooting depth is further restricted by increased rainfall and waterlogging (see Section 3.2.5 above). Additionally if the UK experiences more storms, the return period of damaging events would decrease, i.e. the risk would increase (Della-Marta and Pinto, 2009). Across Europe, damage is expected to at least double over the next century as a result of a combination of increasing standing volume and the effects of climate change (Gardiner *et al.*, 2010). However, projections of changes to wind and storm regime remain uncertain and "there is no consistent signal of change in either storms or blocking near the UK in either 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."²⁵

Wind throw can affect timber prices if the market is glutted with supplies, although the cost of extraction of fallen timber can be significantly higher than for standing timber. In addition, quality can degrade if fallen timber remains on the ground too long, because of the development of stain and decay and through the wood-boring activities of certain insects (Evans *et al.*, 1989). These reduce the uses and value of the timber material. Fallen timber will also affect normal forest operations, and require strategic management plans to be revised. Public access to woodlands may be compromised, because fallen timber presents significant risks to health and safety, as well as the physical obstruction that can occur. There have been no formal assessments of the effects that restrictions in public access pose to the local economies affected. However, experience in the last serious Foot and Mouth outbreak in 2001 suggests that negative effects on tourism could be significant. Other forest ecosystem services may also be compromised.

²⁵ <http://ukclimateprojections.defra.gov.uk/content/view/2126/500/>

3.2.9 Forest fires

Compared to Mediterranean countries, forest fires have not been considered a significant problem in the UK to date, although such fires can be very damaging where they occur. Nevertheless, there were more than 68,000 grass and forest fires in the UK in 2010²⁶, and there is a clear increasing trend of fire frequency over the last three decades (DCLG, 2006). It is estimated that annual cost of wildfires is £7 million in South Wales alone (Forest Research, 2011). Forest fires are usually caused by man, accidentally or on purpose, but the magnitude of these fires is related to weather conditions, and exacerbated by drought, high air temperatures and wind. Climate also affects the provision of 'fuel', in the form of leaf and needle litter to the forest floor and also helps to determine the nature and occurrence of 'mast' years (Övergaard *et al.*, 2007) and thus further provision of fuel. Globally, the likely exacerbating effect of climate change on wildfire and forest fires is causing concern, and considerable research activity (e.g. Winnett, 1998; Flannigan *et al.*, 2000; Cary, 2004; Flannigan *et al.*, 2005; Camia *et al.*, 2008). In the UK, most forest fires will occur in conifer forests, particularly pine, which is more usual in drier, warmer locations such as on heathland areas. Mature broadleaved woodlands are less prone to fires, in part because of the cooler moister conditions prevalent under such canopies. However, young woodlands of both conifers and broadleaved species, where there is substantial ground vegetation, are at greater risk from fire. Intense forest fires may pose a risk to standing trees and the timber resource, but recent fires in Britain tend to be located in the understorey where most damage is caused to wildlife habitat, recreational opportunity and if on organic-rich soils, to carbon storage. In addition, reduction in air quality can cause nuisance and pose a risk to human health, especially if fires are located close to urban communities. Fire can also increase the susceptibility of surviving trees to insect attack, for example secondary bark and ambrosia beetles in conifer forests. Pines damaged by fire are vulnerable to attack by pine shoot beetle *Tomicus piniperda* and possibly the pine bark beetle *Ips sexdentatus* (Långström *et al.*, 1999; Fernandez, 2006).

Research is needed to evaluate the likely effects of climate change on forest fires in the UK. However, most fires occur in 'heat wave' years, and are not easily modelled. In addition, fire risk could be affected by a range of forestry policies which seek to change the nature of the forest canopy, e.g. in Low Impact Silvicultural Systems, and increase the amount of heathland and other non-wooded habitats within forest blocks. Prediction systems will need to take these developments into account, together with any adaptation practices that are specifically designed to reduce fire risk.

3.2.10 Erosion and landslips

Erosion and landslip events cause frequent problems in the UK, and have been particularly evident in recent years in damage caused to the transport infrastructure in Scotland and Wales. The risk of these events is related to a number of factors including land slope angle and type, soil type, soil water content and land use. Most erosion and landslip events follow periods of extreme rainfall.

Forests and woodland can help reduce soil loss by intercepting rainfall and therefore protecting the surface, by removing water from the site through evapotranspiration, and through the enhanced soil strength provided by roots (Norris *et al.*, 2008). Roots bind the soil together and provide cohesion, and the increase in soil strength provided by tree roots can be in the range of 50-70% (Wästerlund, 1989). However, when trees are harvested or die, the subsequent root decomposition leads to decreased cohesion and therefore increased risk of soil loss, compounded by the removal of the protection

²⁶ <http://www.fire-tan.org.uk/ChildSafety/English/EFrame.htm>

provided by tree cover. An additional threat is from wind throw of trees on steep slopes. If soil-root plates are overturned during wind storms, a large volume of soil is displaced down slope and is exposed to further erosion. It is estimated that close to 2000 m³ ha⁻¹ of soil may be displaced down slope as a result of a catastrophic wind throw event in a mature production spruce forest (Nicoll *et al.*, 2005). For these reasons, although trees growing on steep slopes provide a substantial benefit to soil stability, their management requires particular care to maintain their protective function.

In parts of the UK where climate projections indicate that rainfall will increase, erosion and landslips will be expected to increase in frequency (Winter *et al.*, 2010). This may be exacerbated by increased growth rates of trees and increased vulnerability to wind throw from higher water tables and increased storm frequency.

Unless forest management is adjusted to take climate change factors into account on vulnerable forested slopes, the risk of soil loss from erosion and landslide events could increase over the next century. Possible management options to improve resilience and maintain protective function include conversion to continuous cover forestry to maintain root reinforcement of soil, felling trees before they reach heights where their wind risk becomes high, and replacement of stands with slower growing tree species.

As erosion events in the uplands of the UK commonly comprise debris flows that may have a trigger point from a blocked or inadequate culvert, the maintenance of forest culverts is particularly important. In forest areas of the UK where rainfall is expected to increase, consideration should be given to replacement with larger culverts that are adequate for potential extreme rainfall events.

3.2.11 Increased atmospheric carbon dioxide concentrations

The annual mean atmospheric CO₂ concentration for 2010 was 390 parts per million (ppm), and the average annual increase over the decade 2001-2010 was 2 ppm. Over the past 100 years the concentration has increased nearly 100 ppm (33% increase), and is projected to rise by another 90-160 ppm by the 2050s, possibly doubling the pre-industrial concentration of 270-280 ppm (IPCC, 2007). As CO₂ is one of the key environmental variables that limit tree growth, this increase therefore implies that tree growth would be positively affected. Many experimental studies since the 1980s have indeed shown that increasing the ambient CO₂ around plants can increase the growth rate (e.g. Ziska and Bunce, 2006). For example, young trees of several species showed average increases in biomass of approximately 50% when grown in 700-750 ppm CO₂, (Jarvis *et al.*, 2009, p. 26) although these are much higher CO₂ increases than those expected in the next few decades. However, for practical reasons most experiments have been carried out on young plants, and the data for mature trees are very limited (Jarvis *et al.*, 2009). What data there are suggest smaller increases in growth rates than those observed for young trees. In addition, the magnitude of the effect depends upon other environmental variables, particularly temperature, solar radiation and water and nutrient availability. It is likely that in the UK the indirect climate effects of the increased atmospheric CO₂ on rainfall, radiation, temperature and consequently on nutrient cycling will be larger than the effect of the increased CO₂ itself on tree growth. All these factors will interact to affect plant growth.

Tree growth rates in natural or managed ecosystems are also intimately linked with the functioning of the rest of the ecosystem, particularly weeds or other plant competitors, herbivores, pathogens and decomposers. These organisms are critical to growth, survival and nutrient cycling, and they may be affected by increased CO₂ directly, and by the response of the trees themselves (for example, leaf chemical composition can change), and by the continuing changes in climate. Therefore, it is difficult to predict the effect of increased CO₂ alone on tree growth and productivity, although it is highly

likely that growth rates have increased as atmospheric CO₂ has risen and will continue to do so. The growth stimulation effect will be larger in young trees, and those growing before canopy closure, where there is an amplifying effect of increased growth resulting in increased sunlight capture. Therefore, the effect of increased CO₂ is likely to be most significant for shorter rotation tree crops, such as commercial, fast-growing conifers and those for bioenergy. Seed production, seed quality and the growth of seedlings in nurseries is also likely to be improved. The absolute growth increase effect will be larger in conditions where water, temperature or nutrients are not limiting to growth. Thus trees in wetter climates and those on deeper, more fertile soils will show most increase. However, the relative effect on growth may be larger in some more stressed environments (e.g. droughted, nutrient poor), although the commercial consequences may be small, as productivity is low in such conditions.

3.2.12 Increased tourism

There are currently 250-300 million visitors to British forests each year, many undertaking physical activity, resulting in considerable mental and physical health benefits (Quine *et al.*, 2011). An increase in summer temperatures combined with a likely decrease in summer precipitation is likely to lead to an increase in these numbers, with additional/increased levels of benefits. However, tourism numbers may be limited by other climate change impacts such as increased management of forest pests and pathogens leading to restrictions on access to woodlands and increased occurrence of hazards such as wildfires and flooding. The intensification of management of forests and agricultural areas for woodfuel and biofuel may also lead to the need to control visitor numbers to some woodlands and footpaths across open farmland.

4 Response Functions

4.1 Introduction

The purpose of this step is to understand the sensitivity (according to the available evidence) of the selected metrics to changing climate conditions. It was based on a review and synthesis of existing research and modelling outputs and included recording key assumptions and uncertainties related to the assessment.

The forestry sector is influenced by environmental pressures that include, and/or are exacerbated by, climate change, as well as by management approach and changes in social and economic conditions. The response functions described in this section aim to quantify the relationship between climate and each of the four risk metrics identified for analysis in Tier 2. The following approach has been taken in the development of response functions:

- Response functions relate a climate variable to a risk metric. This can be a parameter given by UKCP09 or a complex/derived variable, such as aridity or potential soil moisture deficit that is calculated based on a number of parameters in UKCP09.
- The influence of potential changes in forest management, including adaptation, is not included in the response functions, which focus on the relationship with climate only. Adaptive capacity to climate impacts is considered in Chapter 8.
- The influence of social and economic changes are not included in the response functions, but are considered in Chapter 6.
- The change in risk metric is stated in relation to a baseline of 2010.

This chapter summarises the response functions developed in the CCRA for the following metrics:

- FO1 Forest extent affected by pests and pathogens
- FO2 Loss of productivity due to drought
- FO4 Change in tree species suitability and productivity
- BD12 Increased risk of wildfire (this was originally analysed within the Biodiversity and Ecosystem Services Sector Report (Brown *et al.*, 2012), which is why it has the 'BD' prefix).

The original list of metrics that were considered for analysis included FO3, area affected by wind throw, but this was not taken forward for analysis as the data on wind projections is not sufficiently certain. Section 3.2.8 includes some discussion of this potential impact.

Forest biodiversity loss was identified during Tier 2 as an important impact to consider further, but it was not possible to devise a suitable metric and response function to characterise this. Instead, information is provided from a recent review of likely changes in biodiversity as a result of climate change (Berry *et al.*, 2011; Chapter 3, Box 3.1). Similarly, a metric based on 'change in tree species suitability' was replaced by one considering tree productivity, based on data from the public forest estate in Great

Britain. Full details of the response functions developed in the CCRA are given in Appendix 3.

4.2 FO1 Forest extent affected by pests and pathogens

This metric considers the aerial extent of woodland that could be affected by pests and pathogens, taking 'affected' to mean that the impact of the pest or pathogen is sufficiently severe to cause a significant reduction of productivity, timber quality and/or a change in forest management practice (Chapter 3). An example insect pest, green spruce aphid (*Elatobium abietinum*) and an example fungal pathogen, Red Band Needle Blight (RBNB) (*Dothistroma septosporum*) have been used to explore the likely risk to UK woodlands. These were chosen because there is a relatively good understanding of how climatic variables affect their behaviour (Appendix 3). However, their behaviour cannot be regarded as typical because individual pests and pathogens respond in specific ways to climate. Green spruce aphid impact is controlled by winter temperature and the response function was based on this climate indicator. Summer temperature is one of the controlling factors in the spread of RBNB, and the response function has been built on this basis. It is acknowledged that both *Elatobium* and RBNB respond in complex ways to a range of climatic drivers, so the response functions developed in this study should be regarded with an appropriate degree of caution. Nevertheless, they are considered to be helpful in indicating (Chapter 5) the potential scale of impact that climate change might bring.

4.3 FO2 Loss of productivity due to drought

It is widely recognised that drought influences tree health, growth and tree productivity, though the relationship between drought and productivity (including both timber quantity and quality) is complex, and can lead to both poorer and higher quality timber depending upon site and other circumstances (Section 3.2.2). Ultimately, however, drought can cause tree mortality, often when in combination with other stresses such as pests and pathogens (Read *et al.*, 2009). The response function for this metric was developed using the percentage of severely defoliated trees in regional tree crown condition survey data as an indicator of substantial drought impact and relating this to the calculated previous maximum soil moisture deficit (SMD, Read *et al.*, 2009). The percentage defoliation indicator was then simply scaled to percentage yield loss. The response function cannot take into account the change in yield that would be expected from a potential increase in pest and pathogen damage/mortality directly caused by drought stress in the host tree.

4.4 FO4 Change in tree species suitability and productivity

Climate change is expected to have substantial impacts on tree biology, and hence on survival and growth. In turn, these will determine forest productivity, as measured by the rate of timber volume production. The response of the tree productivity metric to current and projected climate change was explored using Forest Research's Ecological Site Classification for Forestry software tool (Pyatt *et al.*, 2001), at a national and regional scale for the public forest estate across Great Britain. This model uses the climatic variables accumulated temperature and moisture deficit, with information on

windiness, continentality, soil type and fertility and tree species characteristics to calculate suitability, assessed as the potential yield class (YC), which is a measure of maximum stem growth rate (maximum mean annual increment) likely at a particular site. Note also that YC is an indicator of performance for a stand over its rotation, and so caution is required when assigning it to particular time periods of climate change projections. The tool was only applied to the public forest estate because there is reasonable information on soil type for public sector forests. The modelled potential YC was combined with the present areas of each species in the public forest, using the Forestry Commission sub-compartment database information, to estimate potential production and change in production. However, the analysis requires a number of simplifying assumptions in the model, particularly that no biotic impacts (weeds, pests and pathogens) are modelled, no effects of increased CO₂ concentration are included, no extreme events (e.g. windthrow, forest fire) are modelled, and that there is no change in area for each species. In addition, the nature of a national scale analysis incorporates uncertainties linked to the low spatial resolution of the digital data used, and these uncertainties become more apparent moving from national to regional scales, possibly leading to large errors in the results. Nevertheless, the evaluation represents the current best method to identify likely changes in long-term potential production of several main tree species over the next seven decades.

4.5 BD12 Increased risk of wildfire

Wildfires and forest fires can have a profound effect on forest ecosystems, and the delivery of their goods and services (Chapter 3). Analysis of rainfall and fire frequency data from 1984-2001 shows a strong relationship and there is also a strong correlation between the frequency of fires and the 'heat wave' years of 1995, 2003 and 2006. Using the McArthur Forest Fire Danger Index (Dowdy *et al.*, 2009), a predictive model of fire risk based upon weather conditions and soil moisture content, the likelihood of increased fire occurrence across the UK in the 2080s has been explored and tabulated for National Parks in England, Wales and Scotland. The climate changes projected (Chapter 5) relate to annual average change only, so they give no indication of the possible impact of changing interannual variability or extreme events such as heat waves. Nevertheless, the response model gives a useful insight into the possible magnitude of change and when in the future this is likely to occur.

5 Changes with Climate

5.1 Introduction

This chapter describes the analysis of possible outcomes of climate change upon the risk metrics selected in Chapter 3 using the response functions summarised in Chapter 4.

5.1.1 Data used

The following data were used to estimate the impact of climate change with selected climate scenarios:

- Historical climate data (Parker *et al.*, 1992)
- UKCP09 projections data, or for FO4, UKCIP02 projections (from UKCIP)
- Calculated past and projected aridity index from the CCRA water sector analysis (Rance *et al.*, 2012)
- Calculated past and projected potential soil moisture deficit from the CCRA agriculture sector analysis (Knox *et al.*, 2012)
- The response functions for each risk metric (Chapter 4).

The full results for each risk metric are presented in Appendix 3 including some regional breakdowns of data. The sections below provide a summary interpretation of the results. The analysis covers England, Wales, Scotland and Northern Ireland for FO2. Northern Ireland is not included for FO1 as there are no published statistics on forest extent by species, or for FO4 as there are no published model results on species suitability change.

For each metric a scorecard is given at the start of each section to indicate the confidence in the estimates given and the level of risk or opportunity. Confidence is assessed as high (H), medium (M) or low (L). Risks and opportunities are scored either high (3) medium (2) or low (1) (shown to the right). These are given for the lower (l), central (c) and upper (u) estimates for the 2020s, 2050s and 2080s. Further information is provided in Appendix 4. Where estimates are uncertain, or no data are available, this is stated in the scorecard.

M	Confidence assessment from high (H) to low (L)
3	High opportunity (positive)
2	Medium opportunity (positive)
1	Low opportunity (positive)
1	Low risk (negative)
2	Medium risk (negative)
3	High risk (negative)

The lower, central and upper estimates provided in the scorecards relate to the range of the estimated risk or opportunity level. For risk metrics that have been quantified with UKCP09 and response functions, this range relates to the results that are given for the low emissions, 10% probability level (lower); medium emissions, 50% probability level (central); and high emissions, 90% probability level (upper). For the risk metrics that have been estimated with a more qualitative approach, these estimates cover the range of potential outcomes given the evidence provided.

5.2 FO1 Forest extent affected by pests and pathogens

Metric code	Metric name	Confidence	Summary Class								
			2020s			2050s			2080s		
			l	c	u	l	c	u	l	c	u
FO1a	Forest extent affected by red band needle blight	M	1	2	3	2	3	3	2	3	3
FO1b	Forest extent affected by green spruce aphid	M	1	1	2	1	2	2	1	2	3

The results for forest extent affected by pests and pathogens have been calculated with the response functions for red band needle blight and green spruce aphid. The results are presented in the form of most likely magnitude of impact, which is allocated a class from very high to very low impact, where the class definitions are defined in Table 5.1.

Table 5.1 Class descriptions for magnitude of impact for pests and pathogens

Class Number	Class Magnitude	Class Description	
		FO1a Red band needle blight	FO1b Green spruce aphid
5	very high	All pine forests affected: > 400 thousand hectares (>98% of the present day total pine forest area)	All spruce forests affected: > 700 thousand hectares (>91% of the present day total spruce forest)
4	high	200 – 400 thousand hectares affected (49-98% of the present day total pine forest area)	400 – 700 thousand hectares affected (52-91% of the present day total spruce forest)
3	medium	100 – 200 thousand hectares affected (25-49% of the present day total pine forest area)	200 – 400 thousand hectares affected (26-52% of the present day total spruce forest)
2	low	50 – 100 thousand hectares affected (12-25% of the present day total pine forest area)	100 – 200 thousand hectares affected (13-26% of the present day total spruce forest)
1	very low	Baseline: current area (45 thousand hectares) affected and up to 50 thousand hectares (11-12% of the present day total pine forest area)	Baseline: current area (70 thousand hectares) affected and up to 100 thousand hectares (9-13% of the present day total spruce forest)

The interpretation of 'area affected' is the area where pest or pathogen outbreaks cause a significant reduction of productivity or timber quality, or require a significant intervention or change in forest management.

The results at a regional level do not show major geographical variation in the magnitude of impact as the response function was developed at a national scale; in fact the translation of class descriptions for area affected is not meaningful at a regional scale and the values of area affected would have to be scaled by the total area of each species present in the region. Table 5.2 below presents the results at a national scale (for England, Wales, Scotland and Northern Ireland together).

Table 5.2 National (England, Wales, Scotland and Northern Ireland) results for magnitude of impact of sample pests and pathogens

Most likely magnitude of impact of pests and pathogens on forests due to projected change in mean summer temperature

	2020s			2050s			2080s			Emission Scenario
	p10	p50	p90	p10	p50	p90	p10	p50	p90	
Red band needle blight	very low	low	high	very low low low	high high high	very high very high very high	low low high	high very high very high	very high very high very high	low medium high
Green spruce aphid	very low	very low	low	very low very low very low	very low low low	low low low	very low very low very low	low low low	low medium medium	low medium high

The main trends showing in the results are:

- The impact of climate change is greater for red band needle blight than for green spruce aphid. Based on the p50 medium emissions scenario, red band needle blight is likely to reach the high impact level by the 2050s and very high impact by the 2080s, whereas the projected impact of green spruce aphid is low in the 2050s and approaching medium by the 2080s.
- The uncertainty bands on the projected change in temperature do influence the level of impact that is borne out in the results, with different classes often observed for the 10%, 50% and 90% probability levels for each climate change scenario.
- By the 2050s, over half of all pine forests in the UK could be affected by red band needle blight if the pathogen spreads as identified in the response function.
- By the 2080s, all pine forests in the UK could be affected by red band needle blight if the pathogen spreads as identified in the response function.
- By the 2080s, the area of spruce forest in the UK affected by green spruce aphid could more than double from the present day area affected.

5.3 FO2 Loss of productivity due to drought

Metric code	Metric name	Confidence	Summary Class								
			2020s			2050s			2080s		
			l	c	u	l	c	u	l	c	u
FO2	Loss of productivity due to drought	M	1	1	2	1	1	2	1	2	3

The results for the risk metric FO2, loss of productivity due to drought, have been calculated based on potential soil moisture deficit and aridity index. The response functions do not take into account the potential positive impact of mild drought for some fast growing species resulting in a reduction of growth rate and consequent improved timber quality, as there is no quantitative information on which to base such an analysis. Nor do they take into account the positive impacts of rising CO₂ levels and accumulated temperature on increasing productivity (see Chapter 3). The full tables of results are provided in Appendix 3. The main trends indicated by the results are:

- There is not a major difference between the results using potential soil moisture deficit and aridity index, indicating that both of these indicators of

climate dryness have a similar influence on modelled defoliation and productivity.

- The projections show there is approximately a 19% (range 12% to 26%) yield loss caused by drought in south-east England by the 2080s. This compares to a 14% yield loss for baseline conditions (present day).
- The projections show there is approximately a 15% (range 10% to 23%) yield loss from drought in northern Scotland by the 2080s. This compares to a 10% yield loss from drought for baseline conditions (present day).
- The projections show there is approximately an 18% (range 11% to 29%) yield loss from drought in Wales by the 2080s. This compares to a 10% yield loss from drought for baseline conditions (present day).

5.4 FO4 Change in tree species suitability and productivity

Metric code	Metric name	Confidence	Summary Class								
			2020s			2050s			2080s		
			l	c	u	l	c	u	l	c	u
FO4a	Change in tree species suitability and productivity (beech, England)	M	1	1	1	2	2	2	3	3	3
FO4b	Change in tree species suitability and productivity (Sitka spruce, Scotland)	M	1	1	1	1	1	1	3	3	3

Figure 5.1 shows the present potential production on the public forest estate, as modelled using the ESC climatic response function (Chapter 4), and its projected change for the 2050s and 2080s, for several key broadleaved and conifer species. Potential production for each species was estimated as modelled Yield Class multiplied by existing forest area managed by the Forestry Commission for that species. Thus baseline potential production estimates differ between species and countries because of the areas planted, suitability and productivity. The calculations have not included any estimate of changing areas in the future. The projections for the 2050s and 2080s show significant differences between some of the species shown. In general, projected climate could detrimentally affect most conifers in England by the 2050s and Wales by the 2080s, whereas potential production in Scotland is projected to increase, in the case of Sitka spruce, Scots pine and lodgepole pine markedly so. Only Sitka spruce is likely to increase consistently in Wales although Norway spruce is projected to increase in production up to 2050, before falling below baseline in 2080. For broadleaved species, there is a uniform picture of declining production in England, but modest increases in some species in some parts of Scotland. Only ash is projected to yield more in Wales, and only by the 2050s in south Wales.

The broad grouping of results into the three countries hides some important regional differences attributable to climate. This is particularly the case for differences in projected production between the east and the west for species more suited to wetter than drier conditions (e.g. Sitka spruce, Figure 5.2).

The results obtained from using the ESC potential yield response function, based on the key climatic and environmental input variables, show that future climatic change projections may support increased as well as reduced production on the public forest estate, depending on location and tree species. However, the model does not take into account the potential effect from damaging pests and pathogens, nor of other unpredictable or extreme events, in particular wind throw which is an important factor for forestry (see Section 3.2.8). Neither does it account for the likely change in choice of tree species or provenance upon restocking in the future in order to plant species more resilient in future climate conditions.

In order to have information on the areas of species planted, this analysis has used the public forest estate data. However, this does not reveal all possible impacts and risks, because the public estate is only 28% of the total area of woodland in the UK. There are unknown differences in species, site types, soils and management between private and public forests. In some areas such as south-east England, the public forest estate is only 14% of total woodland cover, and is dominated by coniferous species, in contrast to privately owned woodland. Thus Figures 5.1 and 5.2 under-estimate the likely impact on total production in this area where climate change is expected to exert its earliest and largest effect. The projected changes in the productivity per se of particular species can be estimated from Tables A3.14 and A3.15.

Thus the modelled potential production values cannot be used in commercial production forecasting, but they are nevertheless helpful in informing the sector where species adaptation is most important and most urgent.

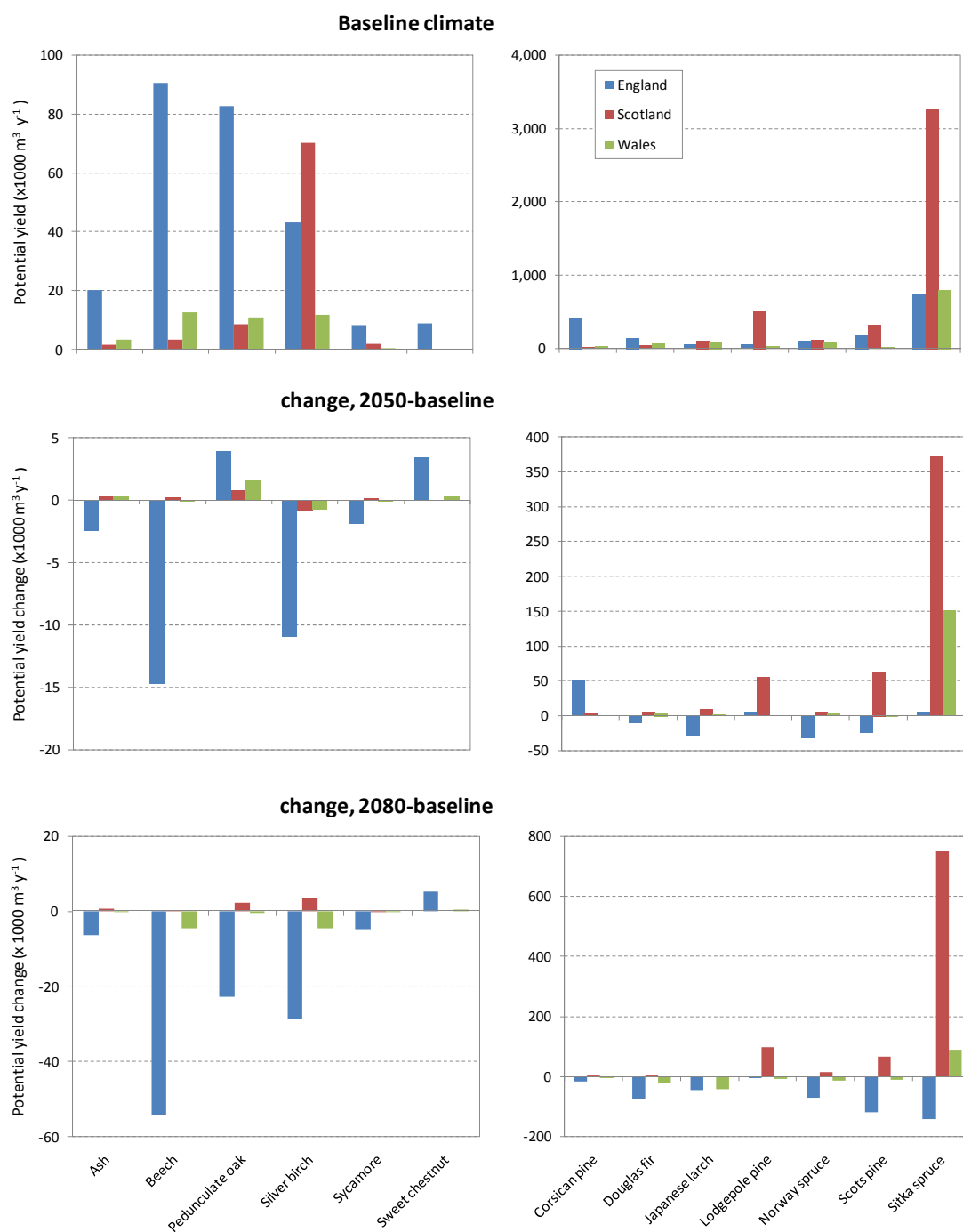


Figure 5.1 Potential production for 1961-1990 climate ('baseline') for selected tree species and the change for projected climate conditions of the 2050s and 2080s on the public forest estate in different countries, assuming areas for each species remain unchanged

(Note the difference in scale between periods and between conifer and broadleaves)

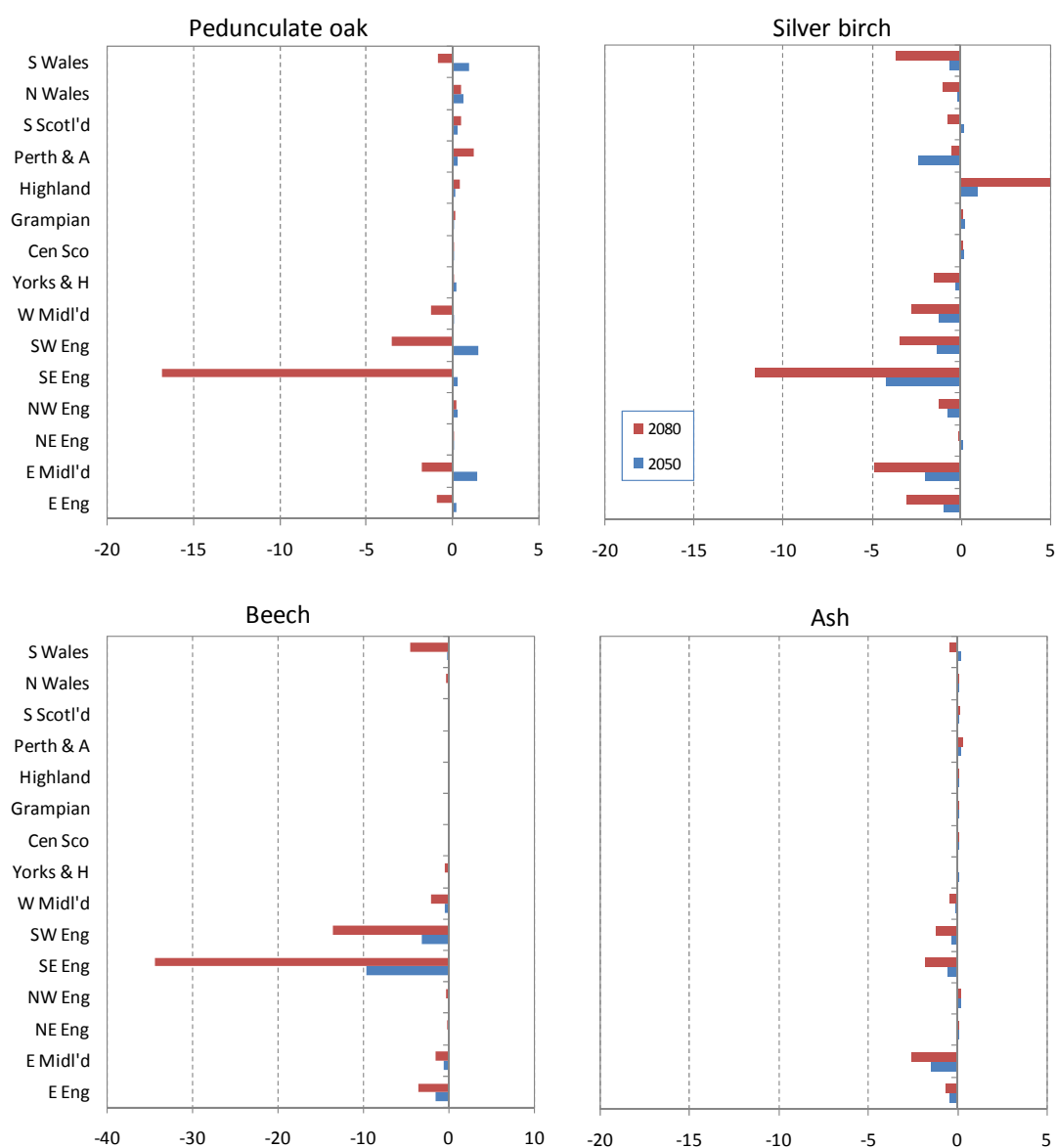


Figure 5.2 Change in potential production ($\times 1000\text{m}^3/\text{yr}$) for projected climate conditions of the 2050s and 2080s for selected broadleaved tree species on the public forest estate in different regions compared to 1961-1990 climate (assuming areas remain unchanged)
(Note the difference in scale for beech)

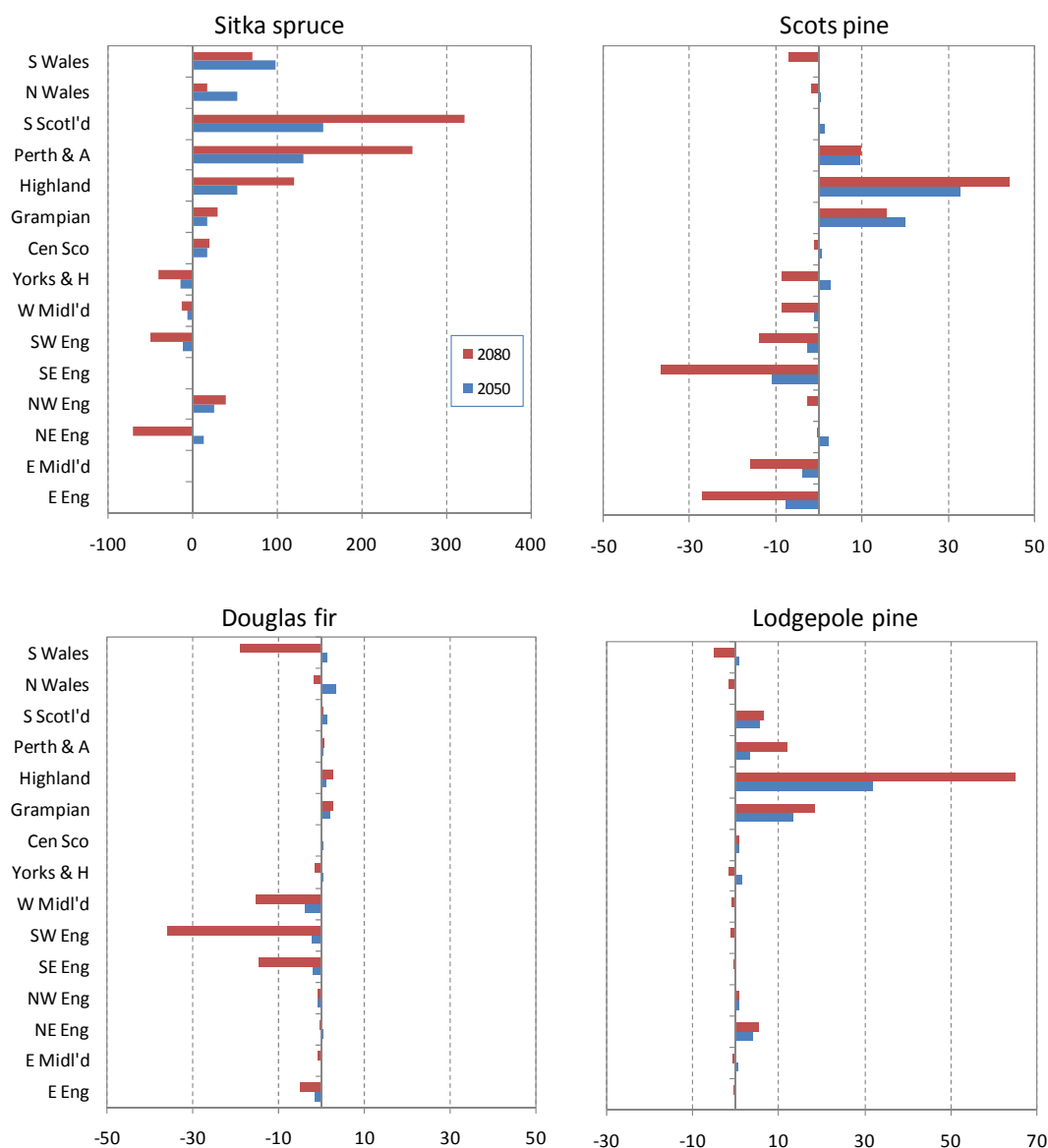


Figure 5.3 Change in potential production ($\times 1000\text{m}^3/\text{yr}$) for projected climate conditions of the 2050s and 2080s for selected conifer tree species on the public forest estate in different regions compared to 1961-1990 climate (assuming areas remain unchanged)

(Note the difference in scale for Sitka spruce)

5.4.1 BD12 Increased risk of wildfire

Metric code	Metric name	Confidence	Summary Class								
			2020s			2050s			2080s		
			l	c	u	l	c	u	l	c	u
BD12	Increased risk of wildfires	M	1	1	2	1	2	3	2	2	3

Development by the Met Office of the McArthur Forest Fire Danger Index (FFDI) for climate change is based upon work carried out originally for the Amazon basin (Golding and Betts, 2008). This has been updated for the UK through use of the 11-member Regional Climate Model (HadRM3) ensemble associated with UKCP09. Within the FFDI scale, a value of 1 means fire will not burn while 5 to 12 is a 'moderate risk'. The system is an Australian one and so values for the UK are lower in the overall scale.

Figure 5.4 shows the projected change in wildfire risk from 1980 to 2080. The results need to be interpreted with caution as they provide only change in annual mean values; it would be assumed that likely values would be higher in the summer months. In addition, the coarse resolution of the soils and land cover data used in the modelling mean that the fuel (biomass) component that is the key element in wildfire risk is probably poorly represented. However, the results show increased fire index values across the UK, with much of southern England moving into an index indicating moderate risk.

To provide an indication of how these national-scale results may affect land managers at the local scale, model results (% difference) have been extracted for national parks across England, Scotland and Wales (Table 5.3).

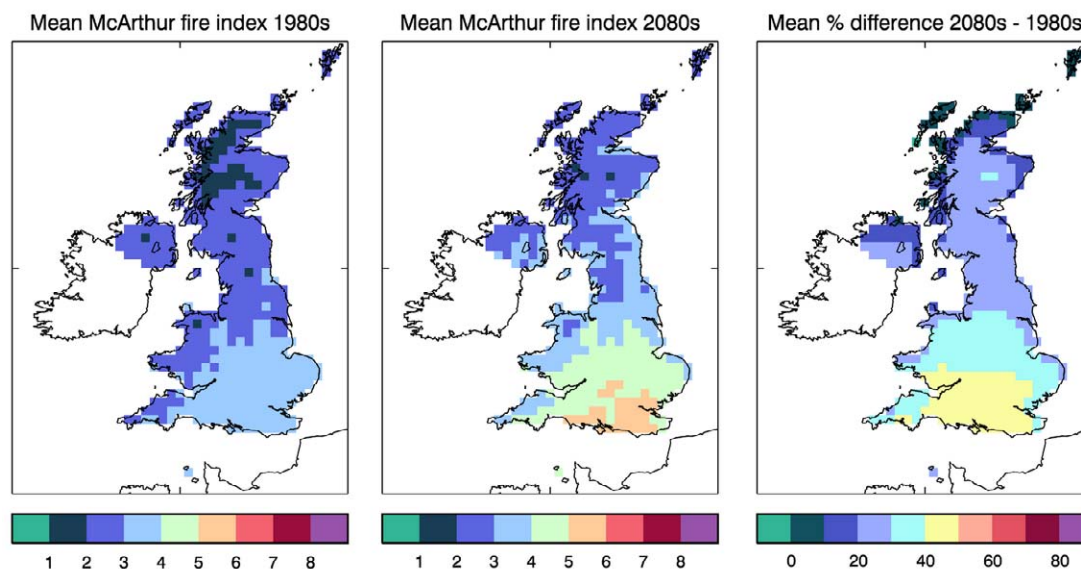


Figure 5.4 McArthur Forest Fire Danger Index for UK using UKCP09 RCM data

(Climate model ensemble mean; medium emissions scenario)

Source: Met Office.

Within the scale, a value of 1 means that fire will not burn while a value of 5 to 9 is considered a 'moderate' risk (note that this is an Australian system and so the values for the UK are lower in the overall scale). Source: Richard Betts, UK Met Office.

Table 5.3 McArthur Forest Fire Danger Index applied to British National Parks

Source: Met Office.

Country	National Park	Mean % difference 2080s – 1980s
England	Lake District	30%
	North Yorkshire Moors	30%
	Northumberland	30%
	The Broads	30%
	Yorkshire Dales	30%
	Exmoor	40%
	Peak District	40%
	Dartmoor	40 – 50%
	New Forest	50%
	South Downs	50%
Scotland	Loch Lomond and The Trossachs	30%
	Cairngorms	30 – 40%
Wales	Pembrokeshire Coast	30 – 40%
	Brecon Beacons	30 – 40%
	Snowdonia	40 – 50%

As noted above, the figures presented are from preliminary analysis of climate model projections and relate to annual average change only, meaning that they give no indication of the possible impact of changing interannual variability or extreme events such as heat waves. More detailed regional analysis of the wildfire risk in the Peak District by Albertson *et al.* (2010) suggested little change in the short term but potentially major changes in fire regime in the medium to long-term. An important interaction with the changing seasonal phenology of vegetation growth and decay was noted which might lead to significant changes in the length and intensity of the ‘at risk’ season. A major limitation is the poor understanding of the applicability of the FFDI model to present UK silvicultural systems, and to those that will be used in the future.

6 Socio-economic Scenarios

6.1 Introduction

Six sets of socio-economic dimensions have been devised to represent socio-economic factors that have the potential to have a significant impact on the forestry sector risks identified. The dimensions are:

- **Population needs/demands (high/low)**
This dimension is intended to encapsulate drivers of population size and distribution (geographically and demographically) and the pressure the population puts onto the country through demands for housing, education etc. One extreme is that there is a high degree of demand on natural, economic and social resources (demand exceeds supply and more people are exposed to risk); the other is that demand is very low (supply exceeds demand and people are less exposed to risk).
- **Global stability (high/low)**
This dimension describes drivers based on world events that would increase or decrease global stability (e.g. war, natural disasters, economic instability). The extremes are higher global stability (with little pressure on governments and people) compared to today, and lower global stability (with a high degree of pressure on governments and people that outweigh other priorities) compared to today.
- **Distribution of wealth (even/uneven)**
This dimension considers the distribution of wealth amongst the British population; the extremes being whether it is more even compared to today, or more uneven (with a stronger gradient between the rich and poor) compared to today.
- **Consumer driven values and wealth (sustainable/unsustainable)**
Globalisation and consumerism are the primary drivers here, specifically movement towards or away from consumerism values. The extremes are that consumers prioritise their time for working and the generation of wealth, with a focus on the consumption of material market goods and services compared to today; and consumers reduce the importance of work and wealth generation in favour of leisure and less materialism, with a focus on the consumption of non-market goods and services such as conservation and recreational activities in green spaces.
- **Level of Government decision making (local/national)**
This relates to how centralised policy making is on adaptation; the extremes being whether there is a completely centralised policy compared to today; or whether there is a very small central Government input and high degree of localism in decision making compared to today.
- **Land use change/management (high/low Government input).**
These dimensions relate to aspects of urbanisation versus rural development. The extremes are that looser planning restrictions might increase development in rural areas (building on the green belt, power stations, etc.) compared to today, versus tighter planning which might increase urban development (more brown field sites) compared to today.

6.2 Influence of socio-economic futures on forestry risk metrics

The influence of the socio-economic dimensions described above on the projected changes of each risk metric in the future has been assessed at a high level, looking forward to the 2080s. The qualitative results of the assessment are provided in Tables 6.1 and 6.2 below. The main sensitivities of the risk metrics to these socio-economic dimensions are:

- The impact of pests and pathogens in the future is very likely to be influenced by socio-economic dimensions, particularly in relation to the demand for trade and timber imports as this is a strong vector for their introduction into the country.
- Adaptive management in the forestry sector is very likely to have a strong influence on the impact of drought (at least in the medium to long-term), as drought-tolerant species can be selected when replanting. This also links to the potential for tree species change and productivity.
- Impacts on biodiversity are virtually certain to be influenced by adaptive management (particularly through tree species selection and diversification for replanting and changes in silvicultural management) and also through changes in recreational use of woodlands.
- Increased size and frequency of forest fires may heighten public interest in climate change, and the need for appropriate adaptation strategies, including where new forests should be planted.
- Consumer driven values are very likely to influence the demand for wood products, which in turn may influence management decisions and species selection when replanting, and the implementation of sustainable forest management practices.
- The level of government decision making will have an impact on how adaptation measures are put in place, which will influence each of the risk metrics.

Table 6.1 below summarises whether the dimensions are relevant or not for forestry metrics and Table 6.2 provides commentary on each dimension/metric combination.

Table 6.1 Relevance of socio-economic dimensions to forestry metrics

	Population needs / demands	Global stability	Distribution of wealth	Consumer driven values and wealth	Government decision making	Land use change / management
FO1 Pests and pathogens	✓	✓	✓	x	✓	✓
FO2 Loss of productivity due to drought	✓	x	x	x	✓	✓
FO4 Change in tree productivity	✓	✓	x	x	✓	✓
BD12 Increased risk of wildfire	✓	x	✓	✓	✓	✓

x Not relevant ✓ Relevant

Table 6.2 Commentary on each socio-economic dimension and forestry metric

Population needs / demands (high / low)	<p>The impact of population needs/demands on forestry relate mainly to the competition for land for food production, nature conservation and timber. The main socio-economic driver which affects the risk of pests and pathogens (FO1) is world (free) trade and the difficulty of restricting imports of different types of imports that carry pests and pathogens (e.g. plants for planting into landscape and horticultural sectors). Water shortages because of (human) water consumption are unlikely to increase risk of drought effects on trees as most trees do not tap into deep ground water. Understanding, however, that some types of tree crop intercept (consume) more water than grass and agricultural crops may lead to some control over new woodland location. Improvements in understanding of different tree species water requirements should lead to appropriate adaptation management which should reduce risk of drought effects (FO2). Public opinion currently influences management decisions regarding tree species choice and thus overall forest productivity (FO4) and this may affect the speed of adaptation, e.g. reluctance to adopt more suitable but exotic tree species. Increasing negative effects of climate change, e.g. acute pest damage or drought effects, may enhance public perceptions about the need for appropriate adaptation. This issue needs careful management. Risk to biodiversity may be influenced by increasing interest in using local green space for recreation, itself an adaptation response to a low carbon economy. Increased population use of forests increases wildfire risk (BD12) which could have a significant effect on timber supply.</p>
Global stability (high / low)	<p>Global stability may affect UK forestry indirectly through international trade of wood and other products. New pests and pathogens (FO1) can be established in the UK from imported wood, wood products and live tree material. A major issue is large proportion of timber needs met through imports and whether forestry policy should be steered towards maintaining or increasing strategic national timber resources. Increasing interest in short rotation forestry (including the use of fast growing non-native tree species) is in part a reflection that the UK needs to have a larger domestic strategic resource. Forest areas managed for biodiversity may be affected if the UK has to plan more strategically around timber shortages and focus more on productivity than some other ecosystem services.</p>
Distribution of wealth (even / uneven)	<p>Widespread tree mortality induced by particular pests or pathogens to specific tree species, if important commercially, could lead to significant liquidation of material assets, and loss of wealth and income. Other forestry risks could have a similar effect, though predicted to be of a lesser potentially maximum extent. The distribution of wealth may influence the increasing interest in provision of local green space (including woods and trees) to local people (maybe without cars) in towns and cities. The main risks identified may compromise this delivery to some extent. Some pests and pathogens are already impacting on urban people, e.g. horse chestnut pathogens and oak processionary moth, though it is unlikely that the poor are disproportionately affected.</p>
Consumer driven values and wealth (sustainable / unsustainable)	<p>An increase in desire to use so-called 'natural' products in construction, such as wood, and increase in interest in non-fossil fuels, such as biomass, will increase demand for forest products and require increased forest area, and/or more yield from existing areas. Demand for use of products from certificated sustainable sources will influence the adaptation agenda. The outcome of changes in consumer driven</p>

	values for the four forestry risks identified is probably neutral if sustainable forest management principles and adaptation policies are maintained.
Level of Government decision making (local / national)	Centralised policy making would facilitate adaptation principles such as 'right tree, right place' at the landscape scale, which would influence all of the risk metrics chosen for study. More power to the landowner (the Big Society, small State principle) is conversely likely to make adaptation more difficult because of the extremely fragmented nature of land and woodland ownership (Chapter 1), and correspondingly more challenging to effect change using current tools (e.g. woodland grants, felling licensing). Outcome for risks identified: adaptation in forestry will require strong government intervention and exposure to risks identified will remain under small State working. Despite an increasing interest in Government Biosecurity Strategies, there is likely to remain a significant residual risk from pests and pathogens (FO1).
Land use change / management (high/low Government input).	Increasing urbanisation may impact on biodiversity as discussed above. Continued interest in horticulture and gardening is likely to exacerbate the risks of pests and pathogens (FO1), because they can be introduced on imported live plant material (Tubby and Webber, 2010). Most woodland areas are unlikely to be affected by increased development. Urbanisation may lead to a requirement for an increase in tree cover to provide shade and other microclimatological benefits, although population pressure may result in higher density housing and less green space. Drought (FO2) is likely to be a bigger issue and this would require particular attention to species choice and possible irrigation during tree establishment. Outdoor fires adjacent to urban dwellings may influence risk perceptions and thus stimulate adaptation response.

7 Costs of Climate Change

7.1 Introduction

Climate change adaptation decisions that are designed to reduce climate change risks inevitably involve making trade-offs concerning the use of scarce economic resources. To the extent that economic efficiency is an important criterion in informing such decision-making, it is useful to express climate change risks in monetary terms, so that they can be:

- assessed and compared directly (using £ as a common metric) and
- compared against the costs of reducing such risks by adaptation.

For the CCRA, a monetisation exercise has been undertaken to allow an initial comparison of the relative importance of different risks within and between sectors. Since money is a metric with which people are familiar, it may also serve as an effective way of communicating the possible extent of climate change risks in the UK and help raise awareness.

Where possible, an attempt has been made to express the size of individual risks (as described in this report) in monetary terms (cost per year) but due to a lack of available data it has sometimes been necessary to use alternative costs (repair or adaption) to provide an estimate. A summary of the results is provided in Table 7.1 below.

A variety of methods have been used to determine the costs. In broad terms, these methods can be categorised according to whether they are based on:

- Market prices (MP)
- Non-market values (NMV) or
- Informed judgement (IJ).

Informed judgement has been used where there is no quantitative evidence and was based on extrapolation and/or interpretation of existing data.

In general terms, these three categories of method have differing degrees of uncertainty attached to them, with market prices being the most certain and informed judgement being the least certain. It is important to stress that the confidence and uncertainty of consequences differs and care must be taken in directly comparing the results. Whilst we attempt to use the best monetary valuation data available, the matching-up of physical and monetary data is to be understood as an approximation only.

Further, some results are presented for a scenario of future climate change only, whilst others include climate change under assumptions of future socio-economic change²⁷. The approach used, and the relative baseline, is stated in Table 7.1. There are also some important cross-sectoral links, or areas where there is the risk of double counting impacts: these are highlighted in the table. The Tier 2 analysis (see early chapters) focused on four key risks for which response functions were evaluated.

²⁷ The combined effects of socio-economic and climate change provides the total risks faced, but care should be taken when attributing the relative (or marginal) risk due to climate change specifically, as this only includes the climate related element.

Summary of Results

Overall, costs range from low (£1 – 9 million/year) to medium (£10 – 99 million/year) for all categories. The highest is likely to be for red band needle blight, where medium cost impacts may be anticipated by the 2080s if no adaptation is put in place. For drought, the coverage is only for south-east England – and the transferability of results to other regions is highly questionable. For change in productivity, an increase in the value of UK timber production of c. £5.7 million is estimated for the 2050s, but by the 2080s, a cost of c. £1.5 million is calculated for the UK as a whole. Adaptation may be particularly important in reducing the impact of changing distributions of tree species – whether this be autonomous or not is an issue that needs to be addressed by further research.

The climate scenarios are those adopted across the CCRA, i.e. the UKCIP02 or UKCP09 scenarios: Low, Medium and High. No specific mitigation scenario additional to what the UK government has committed to has been used in the sectoral analysis. For each climate scenario from UKCP09, a probability density function (PDF) has been generated; the CCRA has generally used data from the 10% (p10), 50% (p50) and 90% (p90) of this PDF, though with some other variations in later time periods.

Table 7.1 Summary of results in £million per annum

(2010 prices, no uplift or discounting) – climate change signal only (no socio-economic change) – relative change from baseline period. Medium emission, p50 unless stated.

Risk metrics	2020s	2050s	2080s	Estimation Method	Confidence ranking	Notes
FO1a Forest extent affected by red band needle blight	-L	-L/M	-M	Non-Market Values	L	Indicative analysis of loss of ecosystem services. Considers future climate on current forest cover and land-use (no socio-economic change), no autonomous adaptation (forest management).
FO1b Forest extent impacted by green spruce aphid*	-L	-L	-L	Market Prices	M	Indicative analysis of market prices. Considers future climate on current forest cover and land-use (no socio-economic change), no autonomous adaptation (forest management). Negligible impact on other ecosystem services assumed.
FO2: Loss of productivity due to drought	-L	-L	-L	Market Prices	L	Considers future climate on current forest cover and land-use, no autonomous adaptation (forest management). Note wider ecosystem services not considered.
FO4: Change in Tree production	NQ	+L	-L	Market Prices	L	Considers future climate on current forest cover and land-use, no autonomous adaptation (forest management). Note wider ecosystem services not considered.
BD12 Increased risk of wildfire	-L	-L to -M	-M	Impacts on ecosystem services	L	Extrapolation from case studies.

Note: - signifies a negative impact or loss; + signifies benefits or cost reductions.

Impact Cost Ranking: NQ = not quantified, L = £1-9m/pa, M = £10-99m, H = £100-999m, VH = £1000m+, ? = not possible to assess.

Monetisation Confidence Ranking:

Ranking	Description	Colour code
High	Significant confidence in the data, models and assumptions used in monetisation and their applicability to the current assessment.	
Medium	Some limitations regarding consistency and completeness of the data, models and assumptions used in monetisation.	
Low	Knowledge base used for monetisation is extremely limited.	

7.1.1 Introduction to Monetisation

The overall aim of the monetisation is to advance knowledge of the costs of climate change in the UK, by generating initial estimates of the welfare effects. The basic approach to the costing analysis is, for each impact category considered, to multiply relevant unit values (market prices or non-market prices) by the physical impacts identified in earlier sections of this sector report. The total value to society of any risk is taken to be the sum of the values of the different individuals affected. This distinguishes this system of values from one based on 'expert' preferences, or on the preferences of political leaders. However, due to the availability of data, it has sometimes been necessary to use alternative approaches (e.g. repair or adaptation costs) to provide indicative estimates.

There are a number of methodological issues that have to be addressed in making this conversion (Metroeconomica, 2004; Boyd and Hunt, 2006) including the compatibility between physical units and monetary units and the selection of unit values that address market and non-market impacts. The aim is to express the risk in terms of its effects on social welfare, as measured by the preferences of individuals in the affected population. Individual preferences are expressed in two, theoretically equivalent, ways. These are:

- the minimum payment an individual is willing to accept (WTA) for bearing the risk or
- the maximum amount an individual is willing to pay (WTP) to avoid the risk.

There are also other issues (beyond this scoping analysis) in terms of impacts that have non-marginal effects on the UK economy, the treatment of distributional variations in impacts, and the aggregation of impact cost estimates over sectors and time.

7.2 Presentation of results, uplifts and discounting

Consistent with other sectors, the indicative results below are presented in terms of constant (2010 prices) for the three time periods considered in the CCRA, i.e. the 2020s, 2050s and 2080s. The results are presented in this way to facilitate direct comparison.

At this stage, the values below are not presented as a present value or equivalent annual cost. However, the use of the values in subsequent analysis, for example in looking at the costs and benefits of adaptation options to reduce these impacts, would need to work with present values. For this, the values below would need to be adjusted and discounted.

7.2.1 FO1a Forest extent affected by Red Band Needle Blight (RBNB)

This metric considers the extent of woodland that could be affected by pathogens, using the analysis of one pathogen species, on one of the major commercial forest types, as an indicator of potential change. The metric assesses the change in the prevalence of RBNB on pine forests.

The discussion of the evidence for this pathogen was presented in Chapter 4. In the absence of data or model outputs on climate impacts on pathogens, this risk metric has been assessed using a semi-quantitative, expert judgement approach.

The results were presented in Chapter 5 and Table 5.2, as the amount of forest affected. The percentage of this area affected by blight in future periods implied from Table 5.2 is presented in Table 7.2. By the 2050s, over half of all pine forests in the UK could be affected by RBNB if the pathogen spreads as identified in the response function, and this could reach 12 – 100% by the 2080s. This has been related to the hectares affected, akin the results from Table 5.2 and applying to a total forest area of 408,000 hectares (Forestry Commission, 2010). This is shown in Table 7.2.

Table 7.2 Summary of impact on Red Band Needle Blight, for England, Wales, Scotland and Northern Ireland, for the 2020s – 2080s, reporting % area affected
(derived from analysis in Table 5.2) and combining with total area at risk, for current forest (no socio-economic change).

% of area affected										
UKCP09 scenario	Base-line	2020s			2050s			2080s		
		p10	p50	p90	p10	p50	p90	p10	p50	p90
Low	11%				11-12%	49-98%	>98%	12-25%	49-98%	>98%
Medium	11%	11-12%	12-25%	49-98%	12-25%	49-98%	>98%	12-25%	>98%	>98%
High	11%				12-25%	49-98%	>98%	49-98%	>98%	>98%

hectares (thousand) affected										
UKCP09 scenario	Base-line	2020s			2050s			2080s		
		p10	p50	p90	p10	p50	p90	p10	p50	p90
Low	44				44-52	200-396	400	52-100	200-396	400
Medium	44	44-52	52-100	200-396	52-100	200-396	400	52-100	400	400
High	44				52-100	200-396	400	200-396	400	400

Note the earlier caveats on the issues of scaling in this way (see Chapter 5). The full results by region are in Appendix 3. It is difficult to relate these numbers to the change in production and market values, as the Tier 2 analysis has not provided these units.

The focus on only one pathogen for one tree type only provides an indicative analysis of the complex relationship between pathogens and forests, and does not account for the wider convergence of potential impacts from pests, socio-economic drivers, other climate impacts (e.g. other metrics affecting tree health and susceptibility), etc. Further, the analysis only considers the direct market effects on commercial species. It does not consider the potential impacts on other goods and services provided by these forests (e.g. recreational activity), or the wider impacts on unmanaged forests and the very considerable ecosystem services that these provide. The analysis is therefore only indicative and partial.

It is highlighted that the results are applied to the current stock. There are planned policy changes that will have major impacts on stocks, as well as many potential changes in relation to land-use and bio-energy, that have implications for the analysis. These need to be considered in future analysis.

Methodology and unit values to be adopted

The most obvious starting point is to look at the market prices for pine wood from managed woodlands, as a unit cost per hectare. It is more difficult to relate this to an annual loss in production because it is not yet clear how much the pathogen reduces timber yield or quality.

Note that in the context of the market prices for timber, any changes to UK prices need to be seen in the context of European and even world timber prices, and supply and demand changes, especially (for here) in the context of the effects of climate change in other regions. This is beyond the scope of this study, but it is highlighted as a key issue.

The study has also considered the potential losses from the current area affected by the pathogen, which is around 45 to 50 thousand hectares. Against this background, monetising the impact of this is difficult – as the impact is to reduce growth and in some cases the disease leads to tree mortality.

Forests provide a number of “ecosystem services” that can be separated into provisioning (including timber), supporting (soil formation, nutrient recycling), regulating (climate regulation, flood protection, water quality regulation) and cultural services (including recreational and educational benefits). The concept of ecosystem services was embedded in the Millennium Ecosystem Assessment (2005) and is also the subject of the UK National Ecosystem Assessment (2011).

Chiabai *et al.* (2009) present estimates of marginal values for forest ecosystem services based on a review of the literature and meta-analysis of studies that have examined different aspects. This study gives the value in per hectare forest terms for a range of biomes around the world. We use the values from Chiabai *et al.* (2009) for Europe for cold coniferous forests (see Table 7.3). The total marginal value of the ecosystem services provided is approximately £334 per hectare. However, this has to be related to the likely reduction in these services, which, as highlighted above, is uncertain.

This illustrates the difficulty in placing monetary values on the impact of RBNB. As a consequence, we assume a proportional impact of exposure per hectare, using the values from Chiabai *et al.* (2009), but recognising the significant uncertainties.

Table 7.3 Forest ecosystem service values: European average

	2007 €/ha	2009 £
Provisioning services	107	80
Carbon sequestration	240	179
Recreational services	1.3	1.0
Passive use	99	74
Total	447	334

Source: Based on Chiabai *et al.* (2009)

Results and discussion

The impact of RBNB on ecosystem services is highly uncertain and is an issue that needs more research – we can only present a range of alternative values at this stage. At maximum, if the forest is destroyed (an unlikely scenario) then all ecosystem services are lost. In Table 7.4 it is assumed that 10% of total ecosystem services are lost because of RBNB, though this is highly uncertain. For the central estimates, the damage costs range from zero to £2 million in the 2020s and up to £12 million by the 2080s.

These estimates do not consider the potential for adaptation, e.g. in terms of moving to different tree species or pest control strategies.

Table 7.4 Estimated change in costs of damage from Red Band Needle Blight by emissions scenario

(£Million/year, 2010 prices, no uplift or discounting) with future climate change (2020s, 2050s, 2080s) assuming current forest stock (no future socio-economic)

£million / year										
UKCP09 scenario	Base-line	2020s			2050s			2080s		
		p10	p50	p90	p10	p50	p90	p10	p50	p90
Low	1.5				0	5-12	12	0-2	5-12	12
Medium	1.5	0	0-2	5-12	0-2	5-12	12	0-2	12	12
High	1.5				0-2	5-12	12	5-12	12	12

7.2.2 FO1b Forest extent affected by green spruce aphid

This metric considers the extent of woodland that could be affected by pests, using the analysis of one pest species on one of the major commercial forest types as an indicator of potential change. The metric assesses the change in the prevalence of green spruce aphid on spruce forests.

The discussion of the evidence for this pest was presented in Chapter 4. In the absence of data or model outputs on climate impacts on pathogens, this risk metric has also been assessed using a semi-quantitative, expert judgement approach.

The extent of this current area affected in future periods has been assessed, and this has been related to hectares affected in Table 7.5 below. This takes the results from Table 5.2, which shows the coverage could reach 9 – 52% by the 2080s. These values are then applied to a total forest area of 770,000 hectares (Forestry Commission, 2010).

Table 7.5 Summary of impact on green spruce aphid, for England, Wales, Scotland and Northern Ireland, for the 2020s – 2080s

reporting % area affected (derived from analysis in Table 5.2 and combining with total area at risk, for current forest (current socio-economic))

% of area affected										
UKCP09 scenario	Base-line	2020s			2050s			2080s		
		p10	p50	p90	p10	p50	p90	p10	p50	p90
Low	10				9-13	9-13	13-26	9-13	13-26	13-26
Medium	10	9-13	9-13	13-26	9-13	13-26	13-26	9-13	13-26	26-52
High	10				9-13	13-26	13-26	9-13	13-26	26-52

hectares (thousand) affected										
UKCP09 scenario	Base-line	2020s			2050s			2080s		
		p10	p50	p90	p10	p50	p90	p10	p50	p90
Low	77				77-108	77-108	108-223	77-108	108-223	108-223
Medium	77	77-108	77-108	108-223	77-108	108-223	108-223	77-108	108-223	223-439
High	77				77-108	108-223	108-223	77-108	108-223	223-439

Again, the earlier caveats on the difficulties in such scaling are noted (see Chapter 5). It is difficult to relate these numbers to the change in production and market values, as the Tier 2 analysis has not provided these units.

Again, the focus on only one pest for one tree type only provides an indicative analysis of the complex relationship between pests and forests, and does not account for the

wider convergence of potential impacts from pathogens, socio-economic drivers, other climate impacts (e.g. other metrics affecting tree health and susceptibility), etc. Further, the analysis only considers the direct market effects on commercial species. It does not consider the potential impacts on other benefits of commercial forests (e.g. recreational activity), or the wider impacts on unmanaged forests and the very considerable ecosystem services that these provide. The analysis is therefore only indicative and partial.

It should be noted that the results are applied to the current stock. There are planned policy changes that will have major impacts on stocks, as well as many potential changes in relation to land-use and bio-energy, that have implications for the analysis. These need to be considered in future analysis.

Methodology and unit values to be adopted

The most obvious starting point is to look at the market prices for spruce wood from managed woodlands, as a unit cost per hectare. It is more difficult to relate this to an annual loss in production because it is not clear how much the pathogen reduces yields or quality, but a general assumption could be made.

Note that in the context of the market prices for timber, any changes to UK prices need to be seen in the context of European and even world timber prices, and supply and demand changes, especially (for here) in the context of the effects of climate change in other regions. This is beyond the scope of this study, but it is highlighted as a key issue.

Given these uncertainties, the analysis here has used previous estimates to try and scope out the potential valuation. Williams *et al.* (2010) estimate the cost of green spruce aphid at £3,569,324 for the UK annually based on an average spruce timber price of £42/m³ and a 3% loss of yield. Dividing this by the area affected in the baseline risk presented in this report gives an estimated cost of £46.35 per hectare affected. This assumes a spruce area of 770,000 hectares in Great Britain (Forestry Commission, 2010). This provides the information to allow an order of magnitude scaling of the impacts.

Results and discussion

Using the previous literature, we estimate damages caused by an increase in green spruce aphid with climate change as shown in Table 7.6. This shows net costs of climate change of between zero and £17 million depending on the scenario. These costs do not consider the potential for adaptation – e.g. in terms of planting different species or aphid control strategies.

Table 7.6 Estimated change in costs of damage from green spruce aphid by emissions scenario

(£Million/year, 2010 prices, no uplift or discounting) with future climate change (2020s, 2050s, 2080s) assuming current forest stock (no socio-economic change)

£million / year										
UKCP09 scenario	Base-line	2020s			2050s			2080s		
		p10	p50	p90	p10	p50	p90	p10	p50	p90
Low	4				0-1	0-1	1-7	0-1	1-7	1-7
Medium	4	0-1	0-1	1-7	0-1	1-7	1-7	0-1	1-7	7-17
High	4				0-1	1-7	1-7	0-1	1-7	7-17

7.2.3 FO2 Loss of productivity due to drought

Chapter 4 presented the response function developed, which relates soil moisture deficit to percentage of severely defoliated trees. Chapter 5 presented the results, reporting the loss of productivity (as a percentage) from drought (note effects on timber quality are not included). The estimated loss of productivity of forests is presented in Appendix 3. We estimate the impact by country²⁸.

Again, the earlier caveats on the difficulties in such scaling are noted (see Chapter 5). It is difficult to relate the full results (Appendix 3) to the change in production and market values, as the Tier 2 analysis has not provided the absolute change, only percentage changes.

The earlier caveats on the complex relationship with droughts, and other factors (e.g. pests and pathogens, socio-economic drivers, other climate impacts such as other metrics affecting tree health and susceptibility), are also highlighted. Further, the analysis only considers the direct market effects on commercial species. It does not consider the potential impacts on other benefits of commercial forests (e.g. recreational activity), or the wider impacts on unmanaged forests and the very considerable ecosystem services that these provide. The analysis is therefore only indicative and partial.

It is highlighted that the results are applied to the current stock. There are many potential changes in relation to land-use and bio-energy, which have implications for the analysis. These need to be considered in future analysis.

Methodology and unit values to be adopted

The most obvious starting point is to look at the market prices for timber, as a unit cost per hectare. To estimate the value of this, the production of softwood and hardwood in the UK, we took regional data on production of timber, as shown in Table 7.7 below. We valued softwood at £9.17 per cubic metre²⁹. For hardwood we assume the value is twice that of softwood³⁰. We adjust for the relative conversion factors for green tonnes to cubic metres for pine (softwood) and beech (hardwood).

Table 7.7 Timber production by country (thousand green tonnes)

Source: Forestry Commission (2010)

	Softwood	Hardwood
England	1,777	468
Scotland	5,206	41
Wales	1,049	24
NI	447	0

Note that in the context of the market prices for timber, any changes to UK prices need to be seen in the context of European and even world timber prices, and supply and demand changes, especially (for here) in the context of the effects of climate change in other regions. This is beyond the scope of this study, but it is highlighted as a key issue.

The response functions do not take into account the potential positive impact of drought on slowing growth and increasing timber quality. Non-market benefits (e.g.

²⁸ South-east England was used as a proxy for the impact on England and Western Scotland for the impact on Scotland as regional data on timber harvesting were not available.

²⁹ Source: based on Forestry Commission timber prices, source:

<http://www.confor.org.uk/NewsAndEvents/Default.aspx?pid=207>

³⁰ Jennifer McVey, pers. comm., Forestry Commission estimate

recreation and other services) are not considered to be majorly affected by drought, so negative impacts on these are not considered here.

The analysis only considers the direct market effects on commercial species. It does not consider the potential impacts on unmanaged forests and the very considerable ecosystem services that these provide. The analysis is therefore only indicative and partial.

Results and discussion

Using this indicative approach, we estimate the damages caused by drought in England, Scotland and Wales³¹ as shown in Table 7.8, as an illustration of the potential valuation. Damages are estimated at between -£0.02 to £8.22 million for Great Britain, i.e. there are relatively small gains or losses because of the impact of climate change on productivity through drought. This should be considered a rather crude estimate. Due to the nature of the climate projections, there is a range of positive and negative effects according to the climate scenarios.

Table 7.8 Estimated loss of productivity caused by droughts for different emissions scenarios

(£Million/year, 2010 prices, no uplift or discounting) with future climate change (2020s, 2050s, 2080s) assuming current forest stock (no socio-economic change)

Location	2020			2050			2080			Emission Scenario
	p10	p50	p90	p10	p50	p90	p10	p50	p90	
Scotland				0.34	1.23	2.31	0.52	1.55	2.82	Low
	-0.08	0.71	1.65	0.54	1.53	2.72	1.04	2.30	3.87	Medium
				0.72	1.78	3.03	1.62	3.13	5.10	High
England				-0.37	0.51	1.49	-0.24	0.64	1.66	Low
	-0.53	0.29	1.17	-0.17	0.65	1.56	0.03	0.86	1.85	Medium
				-0.07	0.69	1.58	0.23	1.10	2.14	High
Wales				0.00	0.22	0.46	0.04	0.27	0.55	Low
	-0.07	0.12	0.33	0.08	0.32	0.60	0.15	0.43	0.76	Medium
				0.08	0.33	0.62	0.24	0.58	0.99	High
GB total				-0.02	1.96	4.26	0.33	2.47	5.03	Low
	-0.68	1.13	3.16	0.45	2.50	4.89	1.22	3.60	6.48	Medium
				0.72	2.80	5.23	2.09	4.82	8.22	High

Notes: - signifies that these are benefits or cost reductions

This also does not consider the potential for adaptation; e.g. in terms of changing tree species or other measures to mitigate the impact of droughts on forests.

7.2.4 FO4 Change in tree species suitability and productivity

Chapter 4 presented the response function developed which projects change in potential productivity with climate by multiplying yield class by the area of each species in the public forest estate (Section 4.4). In this section, the impact on yields is expressed in monetary terms following the steps below. First, the outputs from the risk assessment are presented and discussed. Next, the methodology and the unit values employed to estimate the impacts in monetary terms are outlined. Finally the monetisation results are presented.

Consistent with other sectors, the indicative results below are presented in terms of constant (2010 prices) for two of the three time periods considered in the CCRA, i.e. the 2050s and the 2080s. The results are presented in this way to facilitate direct comparison.

³¹ Noting there was no modelling for Northern Ireland.

At this stage, we have not presented the values below as a present value or equivalent annual cost. However, the use of the values in subsequent analysis, for example in looking at the costs and benefits of adaptation options to reduce these impacts, would need to work with present values. For this, the values below would need to be adjusted and discounted.

Outputs from the Risk Assessment

The output from the physical risk assessment is the baseline yield and projected potential production of different species of hardwood and softwood trees in the public forest estate. The changes in yield are based on the UKCIP02 projections and are from the baseline period of 1961-1990. This information is given in Table 7.9 for hardwood species and in Tables 7.10 and 7.11 for the softwood species.

Looking at the changes in the potential production of hardwood trees we see that for the UK as a whole a decline is projected in the 2050s and the 2080s from the baseline for all species of hardwood trees except for oak in the 2050s and sweet chestnut in both future time periods. A similar trend is also true for England and Wales except that the potential production of ash is projected to increase in Wales in the 2050s. For Scotland an increase in the potential production of all species of hardwood trees is projected in the future time periods from the baseline, except for the potential production of silver birch, which is projected to decline in the 2050s compared to the baseline.

**Table 7.9 Baseline potential production and change in 2050s and 2080s from baseline due to climate change - hardwood trees in the UK
(in m³ per year)**

Region	Ash			Beech			Pedunculate oak			Silver birch			Sycamore			Sweet chestnut		
	baseline	2050s change	2080s change	baseline	2050s change	2080s change	baseline	2050s change	2080s change	baseline	2050s change	2080s change	baseline	2050s change	2080s change	baseline	2050s change	2080s change
<u>GB – all</u>	25,458	-1,849	-5,878	105,448	-13,807	-56,507	101,512	6,563	-20,187	125,982	-13,383	-32,785	10,929	-1,779	-4,977	9,275	3,512	5,393
<u>England – all</u>	20,433	-2,519	-6,258	90,439	-14,697	-54,192	82,544	3,959	-22,640	43,122	-10,952	-28,559	8,319	-1,907	-4,662	9,121	3,428	5,251
<u>Scotland – all</u>	1,676	320	630	3,372	217	193	8,582	792	2,256	70,009	-841	3,625	1,999	172	24	-	-	-
<u>Wales – all</u>	3,460	296	-331	12,572	-78	-4,547	11,042	1,548	-396	11,935	-814	-4,626	618	-48	-312	198	291	349
<u>England – conservancies</u>																		
East England	1,644	-426	-622	5,943	-1,578	-3,487	4,784	208	-930	4,332	-993	-3,037	924	-360	-633	417	119	248
East Midlands	7,170	-1,465	-2,567	3,044	-572	-1,550	15,421	1,389	-1,786	7,568	-1,986	-4,878	1,412	-479	-883	258	97	196
North East England	131	6	-9	785	71	-129	472	76	69	1,177	19	-107	350	41	-44	-	-	-
North West England	869	188	219	1,440	-24	-253	1,891	234	215	4,992	-702	-1,258	388	38	-37	48	21	43
South East England	4,463	-565	-1,787	49,793	-9,616	-34,476	36,717	270	-16,860	12,911	-4,232	-11,553	1,263	-380	-978	6,599	2,367	3,300
South West England	4,235	-340	-1,213	23,723	-3,178	-13,627	17,289	1,468	-3,574	4,401	-1,368	-3,453	1,267	-395	-909	1,609	727	1,184
West Midlands	1,555	-99	-418	3,971	-501	-2,088	6,110	82	-1,304	4,187	-1,242	-2,753	517	-153	-327	425	181	263
Yorkshire and The Humber	1,042	80	-46	2,495	112	-474	1,612	208	21	3,973	-330	-1,484	2,312	-227	-923	14	7	12
<u>Scotland – conservancies</u>																		
Central Scotland	124	32	49	256	28	20	222	47	65	1,778	157	87	177	31	28	-	-	-
Grampian	62	19	39	460	90	122	181	85	150	4,448	205	-20	103	35	45	-	-	-
Highland	178	23	57	212	-6	28	998	145	362	29,901	919	4,988	62	8	21	-	-	-

Region	Ash			Beech			Pedunculate oak			Silver birch			Sycamore			Sweet chestnut		
	baseline	2050s change	2080s change	baseline	2050s change	2080s change	baseline	2050s change	2080s change	baseline	2050s change	2080s change	baseline	2050s change	2080s change	baseline	2050s change	2080s change
Perth and Argyll	894	190	349	1,630	8	-23	5,444	234	1,201	30,278	-2,369	-534	857	6	-88	-	-	-
South Scotland	367	58	120	821	67	22	1,954	254	427	4,068	122	-703	844	73	-18	-	-	-
<u>Wales – conservancies</u>																		
North Wales	534	97	105	2,640	105	-307	3,870	601	449	4,975	-197	-1,018	223	1	-73	39	59	82
South Wales	2,942	196	-452	9,997	-216	-4,440	7,199	950	-852	6,964	-621	-3,639	394	-49	-238	160	234	268

Notes: Positive values (highlighted in light green) in the 2050s and 2080s indicate an increase, and negative values (highlighted in orange) indicate a decrease in potential production from the baseline.

Table 7.10 Baseline potential production and change in 2050s and 2080s from baseline due to climate change - softwood/coniferous trees in the UK (in m³ per year)

Region	Corsican pine			Douglas fir			European larch			Japanese larch		
	baseline	2050s change	2080s change	baseline	2050s change	2080s change	baseline	2050s change	2080s change	baseline	2050s change	2080s change
<u>GB - all</u>	450,746	54,230	-8,914	254,783	527	-	28,977	-3,739	-9,715	263,302	-	-
<u>England - all</u>	412,240	49,428	-	147,392	10,097	-	12,902	-4,477	-	56,779	-	-
<u>Scotland - all</u>	12,150	2,652	5,031	43,708	5,192	5,949	14,082	878	1,271	112,923	9,467	2,128
<u>Wales - all</u>	28,192	1,157	-1,244	67,176	4,765	-	2,012	-216	-810	102,001	2,590	-
<u>England - conservancies</u>												
East England	213,943	14,722	-8,425	10,400	-1,456	-5,037	801	-583	-790	33	-32	-33
East Midlands	62,366	10,432	2,500	1,923	-221	-882	653	-382	-583	1,232	-444	-847
North East England	2,435	779	627	3,494	338	-452	515	-28	-190	7,933	-1,953	-5,597
North West England	5,896	1,304	745	3,489	-857	-1,026	1,258	-281	-100	8,611	-20	-65
South East England	62,378	6,883	-	21,230	-2,181	-	1,958	-992	-1,946	1,058	-1,058	-1,058
South West England	36,615	4,988	-4,358	65,758	-2,223	-	3,905	-1,273	-3,619	14,553	-9,720	-
West Midlands	27,073	6,928	4,227	35,896	-3,946	-	1,542	-528	-1,424	8,544	-7,549	-8,533
Yorkshire and The Humber	5,950	1,506	1,029	6,610	494	-1,388	2,286	1	-868	16,328	-7,561	-

Region	Corsican pine			Douglas fir			European larch			Japanese larch		
	baseline	2050s change	2080s change	baseline	2050s change	2080s change	baseline	2050s change	2080s change	baseline	2050s change	2080s change
<u>Scotland - conservancies</u>												
Central Scotland	127	69	99	309	-14	-90	619	65	-28	4,635	296	-821
Grampian	7,218	3,162	4,790	8,322	2,097	2,743	3,060	504	410	14,665	2,260	1,100
Highland	385	6	95	10,747	1,054	2,751	4,020	121	900	21,098	2,103	1,420
Perth and Argyll	3,160	-210	209	11,993	427	729	4,762	150	247	33,364	1,675	358
South Scotland	1,175	121	215	10,658	1,409	238	1,624	45	-198	39,152	3,259	866
<u>Wales - conservancies</u>												
North Wales	11,890	1,057	314	26,475	3,250	-1,851	905	10	-4	27,216	453	-7,886
South Wales	16,335	-15	-1,675	40,799	1,466	19,131	1,088	-198	-714	75,446	2,221	34,843

Notes: Same as those for Table 7.9.

**Table 7.11 Baseline potential production and change in 2050s and 2080s from baseline due to climate change - softwood trees in the UK
(in m³ per year) (contd.)**

Region	Lodgepole pine			Norway spruce			Scots pine			Sitka spruce		
	baseline	2050s change	2080s change	baseline	2050s change	2080s change	baseline	2050s change	2080s change	baseline	2050s change	2080s change
<u>GB - all</u>	602,803	60,771	86,911	309,630	-23,528	-68,194	524,828	33,271	-79,886	4,783,320	461,273	328,617
<u>England - all</u>	54,112	6,026	96	111,855	-31,656	-68,972	179,309	-24,269	-119,031	734,770	5,808	-141,548
<u>Scotland - all</u>	511,239	55,326	99,450	118,296	5,392	15,510	319,207	63,191	66,690	3,257,748	371,361	748,344
<u>Wales - all</u>	34,050	523	-5,763	80,537	3,425	-13,796	19,842	74	-8,469	801,839	150,852	88,422
<u>England - conservancies</u>												
East England	503	-60	-349	1,149	-959	-1,133	32,269	-7,660	-26,981	21	-7	-20
East Midlands	4,736	517	-623	6,240	-4,660	-6,135	23,492	-3,959	-16,136	3,408	456	-486
North East England	21,897	4,168	5,446	37,905	5,691	2,301	15,846	2,153	-506	417,041	13,792	-70,076
North West England	10,110	880	848	8,503	699	490	8,163	-154	-2,887	163,100	26,319	39,587
South East England	325	-98	-324	15,089	-8,200	-15,019	37,080	11,089	-36,760	560	-366	-560
South West England	1,995	-189	-1,264	27,295	-10,841	-24,702	16,116	-2,889	-14,035	88,978	-10,431	-49,800
West Midlands	1,938	-74	-872	7,864	-3,795	-7,578	14,485	-1,191	-8,708	12,220	-5,454	-11,896
Yorkshire and The Humber	14,452	1,490	-1,438	6,297	-299	-3,218	30,771	2,624	-8,721	65,624	-13,446	-39,596

Region	Lodgepole pine			Norway spruce			Scots pine			Sitka spruce		
	baseline	2050s change	2080s change	baseline	2050s change	2080s change	baseline	2050s change	2080s change	baseline	2050s change	2080s change
<u>Scotland - conservancies</u>												
Central Scotland	10,892	1,019	1,002	5,405	586	48	9,507	718	-1,314	179,022	18,246	19,878
Grampian	44,641	13,278	18,436	16,049	3,865	5,895	88,253	20,026	15,672	217,246	18,195	30,474
Highland	300,556	31,882	64,988	17,118	640	3,510	152,057	32,773	44,237	491,267	53,739	120,617
Perth and Argyll	85,670	3,435	11,920	43,822	-3,481	2,088	54,811	9,475	9,756	1,246,454	131,715	260,744
South Scotland	66,374	5,784	6,450	36,624	3,961	4,148	15,216	1,379	-236	1,144,492	154,451	321,531
<u>Wales - conservancies</u>												
North Wales	12,649	-95	-1,391	32,055	1,319	-2,016	7,112	137	-1,913	373,449	52,847	18,253
South Wales	21,416	864	-5,007	48,567	2,110	-11,833	12,881	-124	-7,246	428,398	98,632	70,988

Notes: Same as those for Table 7.9.

The changes in potential production projected for the 2050s and the 2080s from baseline yield for the coniferous trees in the UK vary by the type of trees considered. A decline in yield is projected for both the 2050s and the 2080s from baseline yield for the UK as a whole for the European larch, Japanese larch and Norway spruce. An increase in yield is projected for both the 2050s and the 2080s from baseline yield for the UK as a whole for lodgepole pine and Sitka spruce. For the Corsican pine, Douglas fir and Scots pine, increases in yields are projected for the 2050s but not for the 2080s when considering the UK as a whole.

A number of assumptions are important in interpreting these results, especially in the context of the subsequent monetisation exercise:

- The potential production is calculated for the public forest estate, and can only be used as an approximate indicator for the whole of the UK. There are unknown differences in species, site types, soils and management between private and public forests which prevent the derivation of a UK-wide indicator.
- The calculated potential production is an indicator of performance for a stand over its rotation, and so caution is required when using it for particular time periods of climate change projections.
- The analysis is undertaken for a scenario of future climate change only: it does not include the effects of future socio-economic change (land-use change, forestry policy including reform, international forestry development, mitigation policy for forestry, etc.). It also does not include potential baseline productivity increases from technological advance, water and irrigation, new species (including GMOs), etc.
- The analysis only considers the direct primary effect of a number of climate variables on yield, using a direct relationship. However, in practice the impact of climate is likely to be much more complex. For example, the relationship between climate, forest growth and yield are complicated by a large number of climate, soil and forest management factors, the effects on pests and pathogens, extreme events and seasonal to daily change, etc.
- The analysis assumes no adaptation, including no forest level autonomous adaptation. In practice forest level responses would reduce impacts through a number of local responses (e.g. alternative cultivars, different species, etc.).
- The analysis also does not consider the effects of climate change internationally and therefore on timber wood markets.

Methodology and Unit Values

To value the changes in forestry potential production, the study has adopted a partial equilibrium approach. This applies direct yield prices only (see later discussion for the caveats with this approach).

The market price of softwood comes from the Forestry Commission (2011c), which provides information on the coniferous standing sales price, i.e. the annual average price (per cubic metre overbark) in real terms in £ in 2006 prices. An average of the most recent five years is taken (2007-2011) to minimise the impact of the annual variation in prices. The annual average sales price of coniferous wood in real terms is £10.75 per m³ in 2010 prices.

The lack of available unit values for hardwood has led us to make a conservative assumption that the value of hardwood is twice that of softwood, i.e. £21.50 per m³ in

2010 prices in line with previous CCRA monetisation work undertaken for the forestry sector.

While this provides an indicative estimate of the monetised value in the UK context, it is important to stress that UK production cannot be seen in isolation of global forestry production and prices that may be impacted by climate change. This is one area where the boundary for the CCRA needs to be extended.

Furthermore, the relative economic impact – and the autonomous response at the local - national scale will depend on what is expected to happen to prices of timber in local national and global markets. To properly assess this, effects have to be analysed in the wider context of what will be happening to the prices of timber as a result of changes in yields worldwide. Furthermore, future prices may change significantly as result of global production trends, socio-economic drivers (population, food production levels, biofuel use, etc.) and from the effects of climate change on production.

Moreover, it is also important to note that the monetary value of forests that we derive by multiplying the projected changes in potential production with the prices of timber reflects only the market value of forests. There are several non-market values (benefits) associated with forests in the UK such as recreational values, landscape values (value of woodland views etc.), the value of biodiversity enhancement, the value of carbon sequestration in forests and the value of air pollution absorption by forests, which would need to be accounted for in order to derive the true monetary value of forests in the UK. Climate change may not only impact the potential production but may also have an impact on the non-market benefits. Although this analysis does not take into account these non-market values since we do not know how the recreational use, landscape use etc. of forests will change in the future, it is important to bear in mind that these values do exist and are important, and that the monetary values presented in the next section only represent market values of forests. Table 7.12 presents some non-market values of UK forests (Willis *et al.*, 2003).

Table 7.12 Annual and capitalised social and environmental benefits of forests in GB (£ millions, 2002 prices)

<i>Environmental benefit</i>	<i>Annual value</i>	<i>Capitalised value</i>
Recreation	392.65	11,218
Landscape	150.22	4,292
Biodiversity	386.00	11,029
Carbon sequestration	93.66 *	2,676
Air pollution absorption	0.39 *	11
Total	1,022.92	29,226

Notes: * An approximation, since carbon sequestration, and probability of death and illness due to air pollution, varies over time. More carbon is sequestered in early rotations than in later rotations, resulting in an annuity stream that is inconsistent over multiple rotations. Similarly for air pollution, that results in an individual's life being shortened by a few days or weeks at the end of the individual's life at some point in the future.

Source: Willis *et al.* (2003).

The magnitude of the non-market values in Table 7.12 indicates that they are substantial and should be taken into account in future studies on the impacts of climate change on forests.

Results and Discussion

Multiplying the unit price identified above by the change in the forestry potential production given in Tables 7.9, 7.10 and 7.11 leads to an estimate of the impact of climate change on forestry revenues in the GB public forest estate. The change in the monetary value of forestry potential production by the 2050s due to climate change for the UK public forest estate is estimated to be a gain of about £5.7 million in 2010 prices (Table 7.13). For Scotland and Wales, the increase in the monetary values of potential production by the 2050s is estimated at £5.5m and £1.8m respectively. For the public forest estate in England, there is estimated to be a decline in the monetary value by the 2050s of £0.9m.

Table 7.13 Change in monetary value (2050s – baseline) of forestry potential production in the GB public forest estate due to climate change (in £ million, 2010 prices)

	Ash	Beech	Pedunculate oak	Silver birch	Sycamore	Sweet chestnut	Corsican pine	Douglas fir	European larch	Japanese larch	Lodgepole pine	Norway spruce	Scots pine	Sitka spruce	Total
	Hardwood						Softwood								
<u>GB - all</u>	-0.04	-0.30	0.14	-0.29	-0.04	0.08	0.58	0.01	-0.04	-0.14	0.65	-0.25	0.36	4.96	5.68
<u>England - all</u>	-0.05	-0.32	0.09	-0.24	-0.04	0.07	0.53	-0.11	-0.05	-0.30	0.06	-0.34	-0.26	0.06	-0.89
<u>Scotland - all</u>	0.01	0.00	0.02	-0.02	0.00	-	0.03	0.06	0.01	0.10	0.59	0.06	0.68	3.99	5.53
<u>Wales - all</u>	0.01	0.00	0.03	-0.02	0.00	0.01	0.01	0.05	0.00	0.03	0.01	0.04	0.00	1.62	1.78
<u>England - conservancies</u>															
East England	-0.01	-0.03	0.00	-0.02	-0.01	0.00	0.16	-0.02	-0.01	0.00	0.00	-0.01	-0.08	0.00	-0.02
East Midlands	-0.03	-0.01	0.03	-0.04	-0.01	0.00	0.11	0.00	0.00	0.00	0.01	-0.05	-0.04	0.00	-0.05
North East England	0.00	0.00	0.00	0.00	0.00	-	0.01	0.00	0.00	-0.02	0.04	0.06	0.02	0.15	0.27
North West England	0.00	0.00	0.01	-0.02	0.00	0.00	0.01	-0.01	0.00	0.00	0.01	0.01	0.00	0.28	0.29
South East England	-0.01	-0.21	0.01	-0.09	-0.01	0.05	0.07	-0.02	-0.01	-0.01	0.00	-0.09	-0.12	0.00	-0.45
South West England	-0.01	-0.07	0.03	-0.03	-0.01	0.02	0.05	-0.02	-0.01	-0.10	0.00	-0.12	-0.03	-0.11	-0.42
West Midlands	0.00	-0.01	0.00	-0.03	0.00	0.00	0.07	-0.04	-0.01	-0.08	0.00	-0.04	-0.01	-0.06	-0.21
Yorkshire and The Humber	0.00	0.00	0.00	-0.01	0.00	0.00	0.02	0.01	0.00	-0.08	0.02	0.00	0.03	-0.14	-0.17
<u>Scotland - conservancies</u>															
Central Scotland	0.00	0.00	0.00	0.00	0.00	-	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.20	0.23
Grampian	0.00	0.00	0.00	0.00	0.00	-	0.03	0.02	0.01	0.02	0.14	0.04	0.22	0.20	0.69
Highland	0.00	0.00	0.00	0.02	0.00	-	0.00	0.01	0.00	0.02	0.34	0.01	0.35	0.58	1.34
Perth and Argyll	0.00	0.00	0.01	-0.05	0.00	-	0.00	0.00	0.00	0.02	0.04	-0.04	0.10	1.42	1.50

	Ash	Beech	Pedunculate oak	Silver birch	Sycamore	Sweet chestnut	Corsican pine	Douglas fir	European larch	Japanese larch	Lodgepole pine	Norway spruce	Scots pine	Sitka spruce	Total
	Hardwood						Softwood								
South Scotland	0.00	0.00	0.01	0.00	0.00	-	0.00	0.02	0.00	0.04	0.06	0.04	0.01	1.66	1.84
<u>Wales - conservancies</u>															
North Wales	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.03	0.00	0.00	0.00	0.01	0.00	0.57	0.65
South Wales	0.00	0.00	0.02	-0.01	0.00	0.01	0.00	0.02	0.00	0.02	0.01	0.02	0.00	1.06	1.14

Note: Positive values (highlighted in green) indicate gains and negative values (highlighted in red) indicate losses. Where the losses or gains are lower than two decimal places, i.e. they are 0.00 in the table above, the shading in green or red shows whether these are gains or losses respectively.

Table 7.14 Change in monetary value (2080s – baseline) of forestry potential production in the GB public forest estate due to climate change (in £ million, 2010 prices)

Region	Ash	Beech	Pedunculate oak	Silver birch	Sycamore	Sweet chestnut	Corsican pine	Douglas fir	European larch	Japanese larch	Lodgepole pine	Norway spruce	Scots pine	Sitka spruce	Total
	Hardwood					Softwood									
<u>GB - all</u>	-0.13	-1.21	-0.43	-0.70	-0.11	0.12	-0.10	-0.93	-0.10	-0.76	0.93	-0.73	-0.86	3.53	-1.48
<u>England - all</u>	-0.13	-1.17	-0.49	-0.61	-0.10	0.11	-0.15	-0.80	-0.11	-0.48	0.00	-0.74	-1.28	-1.52	-7.47
<u>Scotland - all</u>	0.01	0.00	0.05	0.08	0.00	-	0.05	0.06	0.01	0.02	1.07	0.17	0.72	8.04	10.30
<u>Wales - all</u>	-0.01	-0.10	-0.01	-0.10	-0.01	0.01	-0.01	-0.22	-0.01	-0.45	-0.06	-0.15	-0.09	0.95	-0.25
<u>England - conservancies</u>															
East England	-0.01	-0.07	-0.02	-0.07	-0.01	0.01	-0.09	-0.05	-0.01	0.00	0.00	-0.01	-0.29	0.00	-0.64
East Midlands	-0.06	-0.03	-0.04	-0.10	-0.02	0.00	0.03	-0.01	-0.01	-0.01	-0.01	-0.07	-0.17	-0.01	-0.50
North East England	0.00	0.00	0.00	0.00	0.00	-	0.01	0.00	0.00	-0.06	0.06	0.02	-0.01	-0.75	-0.74
North West England	0.00	-0.01	0.00	-0.03	0.00	0.00	0.01	-0.01	0.00	0.00	0.01	0.01	-0.03	0.43	0.38
South East England	-0.04	-0.74	-0.36	-0.25	-0.02	0.07	-0.13	-0.16	-0.02	-0.01	0.00	-0.16	-0.40	-0.01	-2.23
South West England	-0.03	-0.29	-0.08	-0.07	-0.02	0.03	-0.05	-0.39	-0.04	-0.15	-0.01	-0.27	-0.15	-0.54	-2.06
West Midlands	-0.01	-0.04	-0.03	-0.06	-0.01	0.01	0.05	-0.16	-0.02	-0.09	-0.01	-0.08	-0.09	-0.13	-0.68
Yorkshire and The Humber	0.00	-0.01	0.00	-0.03	-0.02	0.00	0.01	-0.01	-0.01	-0.18	-0.02	-0.03	-0.09	-0.43	-0.82
<u>Scotland - conservancies</u>															
Central Scotland	0.00	0.00	0.00	0.00	0.00	-	0.00	0.00	0.00	-0.01	0.01	0.00	-0.01	0.21	0.21
Grampian	0.00	0.00	0.00	0.00	0.00	-	0.05	0.03	0.00	0.01	0.20	0.06	0.17	0.33	0.86
Highland	0.00	0.00	0.01	0.11	0.00	-	0.00	0.03	0.01	0.02	0.70	0.04	0.48	1.30	2.68
Perth and Argyll	0.01	0.00	0.03	-0.01	0.00	-	0.00	0.01	0.00	0.00	0.13	0.02	0.10	2.80	3.09

	Ash	Beech	Pedunculate oak	Silver birch	Sycamore	Sweet chestnut	Corsican pine	Douglas fir	European larch	Japanese larch	Lodgepole pine	Norway spruce	Scots pine	Sitka spruce	Total
South Scotland	0.00	0.00	0.01	-0.02	0.00	-	0.00	0.00	0.00	0.01	0.07	0.04	0.00	3.46	3.58
<u>Wales - conservancies</u>															
North Wales	0.00	-0.01	0.01	-0.02	0.00	0.00	0.00	-0.02	0.00	-0.08	-0.01	-0.02	-0.02	0.20	0.02
South Wales	-0.01	-0.10	-0.02	-0.08	-0.01	0.01	-0.02	-0.21	-0.01	-0.37	-0.05	-0.13	-0.08	0.76	-0.30

Note: Positive values (highlighted in green) indicate gains and negative values (highlighted in red) indicate losses. Where the losses or gains are lower than two decimal places, i.e. they are 0.00 in the table above, the shading in green or red shows whether these are gains or losses respectively.

The change in the monetary value for the GB public forest estate by the 2080s (Table 7.14) due to climate change is estimated to be a loss of about £1.5 million in 2010 prices. For England and Wales, the decrease in the monetary values by the 2080s due to climate change is estimated at £7.5m and £0.3m respectively. For Scotland, there is estimated to be an increase in the monetary value by the 2080s of £10.3m.

It is important to note that the above projected changes do not represent welfare changes since they are not based on the 'gross margin', i.e. the revenue minus the cost. Whilst we do not have the data for gross margins for timber, those for other agricultural crops indicate that they might be expected to be typically 0.3 – 0.5 of the revenue changes projected above.

Moreover, it is also important to note that the above values represent market values only. Non-market values have not been taken into account. The decline in woodland in the future as a result of climate change could lead to high losses in the non-market benefits of forests. This needs to be borne in mind.

Based on the ranking used in this study (Table 7.1), the monetary impacts of climate change on forestry production estimated above for the UK would be 'Low', using the gross margin-adjusted totals.

7.2.5 BD12 Increased risk of wildfire

Wildfire may have a profound effect on forest ecosystems, and their wildlife habitats and species where they occur (Chapter 3). Preliminary modelling of climate change effects on fire danger using the McArthur Forest Fire Danger Index (FFDI) has been undertaken (Chapter 4 and 5). However, these results have not been converted to quantitative estimates of the incidence of fires. Similarly, the risk assessment does not quantify the effects that such incidence might have on biodiversity and other ecosystem goods and services. Instead, the risk assessment is qualitative and monetary analysis was therefore not possible. Further work is required to establish the current total cost of wildfires. Annual costs of simply responding to UK wildfires by the Fire and Rescue Services have been estimated at between £35m³² to c. £49m, but these figures increased by 30% to 60% in heat wave years (e.g. 2003 and 2006) (R. Gazzard, pers. comm.).

There are two distinct size-duration categories of fire; small '4-hour' fires of typically less than 15 ha, and large '3-day' fires of over 350 ha. From a preliminary study of fourteen fires, the former category has been estimated to cost Fire and Rescue Services around £15,000, and the latter £210,000. Such figures exclude helicopter costs, damage to property, livelihoods and other ecosystem services, therefore they represent a significant underestimate. Suppression costs for the April 2003 fire on Bleaklow in the Peak District (which covered 7.4km²) were estimated at approximately £500,000. Restoration costs of woodland habitats is approximately £7,800 per ha (creation costs approximately £7,400 per ha). In addition to the re-establishment of habitat, land cover restoration after wildfire may provide ecosystem services such as carbon sequestration (although this effectively replaces the lost carbon), improvement of water quality to its previous state, and restoration of amenity value, including for recreation (Brown *et al.* 2012). However, these costs do not include impacts of wildfires on infrastructure and social, economic and environmental assets.

³² <http://www.frsug.org/reports/Harrogate2010Gazzard.pdf>

8 Adaptive Capacity

8.1 Overview

Adaptive capacity considers the ability of a system to design or implement effective adaptation strategies to adjust to information about potential climate change, to moderate potential damages, to take advantage of opportunities, or to cope with the consequences (Ballard, 2009, after IPCC, 2007). This can be considered as having two components; the inherent biological and ecological adaptive capacity of ecosystems and the socio-economic factors determining the ability to implement planned adaptation measures (Lindner *et al.*, 2010). Socio-economic factors that determine adaptive capacity to climate change include economic development, technology and infrastructure, information, knowledge and skills, institutions, equity and social capital (McCarthy *et al.*, 2001). This chapter focuses on the socio-economic factors, and in particular, the institutional preparedness of the UK forestry sector to respond to the need to adapt.

Considering adaptive capacity is essential for adaptation planning and the CCRA project has included work in this area that will contribute to the ongoing Economics of Climate Resilience study and the National Adaptation Programme. The CCRA work on adaptive capacity focuses on structural and organisational adaptive capacity and this chapter provides an overview of the assessment approach. The subsequent sections of this chapter provide an overview of the findings from other work on adaptive capacity in the forestry sector that has been carried out.

The climate change risks for any sector can only be fully understood by taking into account that sector's level of adaptive capacity. Climate change risks can be reduced or worsened depending on how well we recognise and prepare for them. The consequences of climate change are not limited to its direct impacts. Social and physical infrastructure, the backdrop against which climate change occurs, must also be considered. If such infrastructure is maladapted, the economic, social or environmental cost of climate impacts may be much greater; other consequences could also be considerably more detrimental than they otherwise might have been. Avoiding maladaptation is one outcome of high adaptive capacity; high adaptive capacity lowers the negative consequence of climate impacts. Conversely, low adaptive capacity increases the negative consequences.

8.2 Assessing structural and organisational adaptive capacity

The methods used for assessing structural and organisational adaptive capacity in the CCRA are based on the PACT framework³³. The work included a preliminary literature- and expert interview-based assessment of all eleven sectors in the CCRA. This was followed by more detailed analysis for the following sectors:

- **Business, Industry and Services** (focusing on the finance sector)
- **Transport** (focusing on road and rail)
- **Built Environment** (focusing on house building)
- **Health**
- **Biodiversity and Ecosystem Services**
- **Water**

³³ PACT was developed in the UK as one of the outcomes of the ESPACE Project (European Spatial Planning: Adapting to Climate Events) <http://www.pact.co/home>.

Structural adaptive capacity

This is the extent to which a system is free of structural barriers to devise and implement effective adaptation strategies to prepare for future impacts. It covers issues such as:

Decision timescales: This considers the lifetimes of decisions, from their conception to the point when their effects are no longer felt. The longer this period is, the greater the uncertainty as to the effects of climate change impacts. Cost-effective adaptation becomes harder. Potential climate impacts also become more extreme over longer timescales. This means that a greater scale of adaptation may need to be considered, and that the barriers to adaptation resulting from 'lock-in' to maladapted processes become more pronounced (Stafford-Smith *et al.*, 2011). Adaptive capacity is therefore lower, and maladaptation more likely, when long-lasting decisions are taken.

Activity levels: This considers what opportunities are there for adaptation, and on what scale. The frequency with which assets are replaced or created determines how many opportunities there will be to take action which increases adaptive capacity.³⁴ In addition, when a lot of asset replacement and/or new investment is expected, there will be more chances to learn from experience, which increases adaptive capacity.

Maladaptation: This evaluates the effect of decisions already made on adaptive capacity. Long-term previous decisions which have reduced adaptive capacity are often difficult or expensive to reverse. Such decisions were made either before climate change was recognised as an issue, or more recently as a result of poor organisational capacity. Such maladaptation makes implementing effective strategies much harder.

Sector (or industry) complexity: This refers to the level of interaction between stakeholders within an industry, or with outside industries and groups, that is required to facilitate effective decision-making. Complexity is higher (and adaptive capacity lower) when many stakeholders are involved in decision-making and when their agendas (e.g. their financial interests) differ substantially.

Organisational adaptive capacity

Organisational adaptive capacity is the extent to which human capacity has developed to enable organisations to devise and implement effective adaptation strategies. Effective adaptation requires decision-making that takes account of an uncertain future and avoids locking-out future options that might be more cost-effective if climate impacts become more severe, or arrive more rapidly, than expected. The PACT framework used to assess this recognises different levels of adaptation. This framework is arranged in a hierarchy of 'Response Levels' ('RLs'), as set out below, of increasing capacity³⁵. These levels do not supersede one another; instead, each one builds on the experiences and practices built up in the previous response level. Organisations may need to be active on all levels for an effective adaptation programme. An RL4 organisation focused on breakthrough projects still needs to be stakeholder-responsive, for example.

RL1: Core Business Focused: At this level, organisations see no benefit from adapting; if change is required of them, it should both be very

³⁴This differs from 'Decision timescales' because investment in a sector is not continuous but varies over time, with periods of high investment being followed by periods of little or no investment.

³⁵ The PACT framework contains six response levels: those cited are the most relevant to the adaptation field.

straightforward to implement and also incentivised, e.g. through ‘carrots’ and ‘sticks’.

RL2: Stakeholder Responsive: At early stages of adaptation, organisations lack basic skills, information, processes and also skilled people; they need very clear advice and information plus regulations that are straightforward enough to help them get started.

RL3: Efficient Management: As organisations begin to professionalise adaptation, they become more self-directing, able to handle short term impacts up to 10 years (Stafford-Smith *et al.*, 2011). They need professional networks, best practice guidelines, management standards, etc.

RL4: Breakthrough projects: When impacts beyond 10 years need to be considered, organisations may need to consider more radical adaptation options. As well as high quality support from scientists, they may need support with the costs of innovation.

RL5: Strategic Resilience: Adapting a whole region or industry for long-term climate impacts of 30 years or more requires lead organisations to develop very advanced capacity that is able to co-ordinate and support action by a wide range of actors over programmes that are likely to last for many years.

8.3 Characteristics of adaptive capacity in the forestry sector

The structural adaptive capacity of the forestry sector is characterised as follows:

- Decision timescales are generally long due to the long growing period and lifetime of trees. Trees planted today need to be capable of surviving in future climatic conditions.
- There are a range of opportunities and barriers to adaptation, as outlined in Section 8.6.
- Maladaptation may be an issue in the future as the long decision lifetimes mean that tree species planted decades ago may be maladapted to future climate conditions.
- The sector complexity is characterised by some strong lead organisations (e.g. the Forestry Commission) and large landholdings (i.e. woodland owned by the Forestry Commission) as well as a large proportion of UK forest that is owned by multiple small landowners.

The organisational adaptive capacity is demonstrated through a range of actions dating back to 1990 and the first Climate Change Impact Review Group Report (see Section 8.4). The forestry sector has always needed to consider long timescales in its planning processes.

8.4 Progress in adaptation

As evidence of adaptive capacity, adaptation actions recommended from the Climate Change Impact Review Group (CCIRG) Reports of 1990 and 1996 (CCIRG, 1990, 1996; Parry, pers. comm.) have been reviewed to provide an historical perspective of adaptation progress during the 1990s, and the capacity of the sector to respond to

adaptation need. This chapter summarises the findings of these reports. The principal adaptation action recommended by CCIRG in 1990 was:

- Consider more short-rotation and mixed species.

The adaptation actions recommended by CCIRG in 1996 were:

- Some policy decisions are needed now (e.g. regarding planting different species)
- National perspective needed to include several issues, e.g.:
 - altered species composition in planting
 - lower stand densities in southern UK
 - use of more southerly provenances and drought tolerant species
 - reduced quality of hardwood supply
- Research: with process-based models, scaling up to regional level, and with economics.

There has been good progress against these recommended actions, because most of them are being put into practice through research, policy and practice in the forestry sector (see Chapter 1; Chapter 9; Read *et al.*, 2009; Forestry Commission Scotland, 2009; Forestry Commission England, 2011a; Forestry Commission, 2011e).

8.5 Adaptive readiness

The potential magnitude of impacts relating to climate change requires further research in order to be better understood. Research into climate change impacts is being driven by the devolved government administrations, and senior management and policy development takes climate change fully into account. A series of initiatives are in place to integrate climate change adaptation into normal forestry management practice, though there is obvious work to do to accomplish this.

Additional evidence of the state of sectoral adaptation preparedness comes from a European-wide survey undertaken on behalf of the European Forest Institute in 2008 (Lindner *et al.*, 2008). The UK response to a questionnaire survey is given in Table 8.1 below, but even just three years later there would be several measures that could now be described as on-going rather than planned.

Finally, a survey of sectoral responses to adaptation in Scotland (Scottish Government, undated) has suggested that the sector is relatively well prepared compared to some other sectors, with a range of appropriate policies and instruments in place or well advanced.

Table 8.1 Status of adaptation to climate change. Detailed UK response with listing of adaptation measures
(from: Lindner *et al.*, 2008)

Regeneration, Afforestation, Nurseries and tree breeding				
O	Ps	Pl	N	Measure
x				Trails of non-local provenances
		x		Selective tree breeding
		x		Identify better adapted species
Tending and thinning				
O	Ps	Pl	N	Measure
		x		Modify silvicultural systems e.g. shorter rotations
Harvesting				
O	Ps	Pl	N	Measure
		x		Consider longer forwarder routes to avoid the need to build forest roads
Management planning				
O	Ps	Pl	N	Measure
	x			Developing species choice
		x		Changing rotation length
Infrastructure and transport				
O	Ps	Pl	N	Measure
x		x		Alternative transport systems
Forest protection against biotic and abiotic factors				
O	Ps	Pl	N	Measure
x				Develop rapid reaction plans
Protected forests				
O	Ps	Pl	N	Measure
x	x			Support for forest habitat networks
Recreational use of forests and other goods and services				
O	Ps	Pl	N	Measure
	x	x		Examination of the recreational provision across the forest estate
Research and monitoring				
O	Ps	Pl	N	Measure
x	x	x	x	Commission CC related research
Training, education and communication				
O	Ps	Pl	N	Measure
x				Conferences and workshops
x	x			Establish a Climate Change Centre as a source of CC knowledge

Key: O: on-going measure; Ps: planned measure in short term; Pl: planned measure in long term; N: new idea

8.6 Barriers and opportunities

The general consensus about the forestry sector's reasonably good preparedness for adaptation identified above should be placed amidst an assessment of the overall political, cultural and economic 'environment' in which adaptation must take place. The following sections summarise important barriers to and opportunities for adaptation.

8.6.1 Barriers

Many barriers to uptake of adaptive measures were noted by stakeholders consulted in Phase 1 (Moffat and Morison, 2009). They can be grouped into the following typology:

General

1. Uncertainty at many levels:

- Over the extent, timescale and causes of climate change (although there is quite a wide acceptance amongst practical foresters that climate change is happening from their own personal observation).
 - Over implications for tree growth and productivity, and for the wider sector which is already dealing with uncertainties over timber markets and globalisation.
 - Over the lack of firm evidence to support proposed adaptive measures such as new species and new silvicultural practices.
 - In the policy landscapes for forestry, notably in England where uncertainty over the future ownership, management and objectives of the public forest estate and wider forestry policy may act as a short term barrier to the implementation of adaptation measures.
2. The long time-frame of tree growth in general, and for forest planning in particular; the need for adaptation measures to be appropriate to both present and future climates, and to fit into current and possible future policy environments, and to fit into current forestry management timescales. It should be realised that the current low level of new planting and restocking across the UK means that the opportunities for adapting through species choice, for instance, are very small. In England, only a maximum of 0.5% of the woodland area could be 'adapted' in any one year by replanting or restocking measures.
 3. Conservative attitudes of the forestry sector and land-use sectors in general. For example:
 - The elements within various nature conservation bodies that will only accept native tree species planting and in some cases only local provenance material, and the dominance of arguably outdated ecological thinking on native *versus* non-native species.
 - Resistance by the public to new technologies that might be helpful, which can prevent even the examination of those technologies (e.g. GM tree material, GM approaches to pest and disease control).

Information and resource availability

4. The lack of information available on adaptation options for those working at an operational level; most dissemination to date has targeted research-level audiences, with operational-level information and decision support tools now beginning to emerge.
5. Weak fiscal drivers to expand or change woodland and forests.
6. Unavailability of different planting material in nurseries; material that may be more 'adapted' to future climate conditions (e.g. new species or provenances from more southerly locations). In addition, there is a two to three year lead-in time for material to be provided by forest nurseries.
7. Lack of sufficient research funding now and in the recent past to enable medium and long-term research to be implemented to provide evidence for guidance and policy support on adaptation measures.

Organisational barriers include:

8. Difficulties in reaching small woodland owners whose main interests may be elsewhere (e.g. agriculture).

9. Area-based forestry incentives – rather than specific targeted incentives.
10. Existing legislative control of forestry activities is weak as it mainly covers the granting of felling licences, and the provision of grants for replanting, where applicants must conform to what is laid down in the UK Forestry Standard. This mechanism therefore only covers woodland under active management or where the landowner seeks a grant for new woodland establishment. Thus much unmanaged woodland, especially in England, is effectively outside legislative control at present.
11. The absence in most of the UK of an integrated spatial land-use strategy, the exception being in Scotland (Scottish Government, 2011b). Thus, decisions about new woodland establishment are generally made at a site-specific scale, and rarely considered at a landscape scale where more optimal land-use could be achieved.
12. Current Common Agricultural Policy mechanisms can inhibit new woodland establishment by encouraging agricultural husbandry. In addition, an EU forestry strategy, that might counterbalance other land use interests and promote the forestry sector, is in the process of revision³⁶ and European Commission attempts to explore a European approach to forest protection from climate change have not been supported³⁷.

In addition to specific barriers identified as relevant to the UK, Lindner *et al.* (2010) discuss some generic forestry adaptation issues, and these are listed below:

13. External factors such as globalisation and demands for rationalisation and profitability are constraining adaptive capacity (Keskitalo, 2008). Immediate loss of revenue and/or lack of financial resources to effect change may cloud perceptions and hinder it.
14. Lack of economic activity in parts of forestry and of systems for the remuneration of forest social and environmental services will constrain adaptive capacity, especially in the private sector, and where woodlands are a marginal part of a landowner's estate.
15. Forest ownership will influence adaptive capacity: management traditions and decision making structures are more variable in privately owned forests compared to the public forest estate. Individual forest management decisions may support inherent adaptive capacity as described above, but small and fragmented privately owned forests are often poorly managed, constituting a barrier to uptake of new adaptive management practices.
16. Availability or shortage of forestry sector work force is another socio-economic factor that may constrain adaptive capacity, together with the education level of forest workers within the sector.
17. Adaptive capacity is strongly limited where large forest areas are only extensively managed or unmanaged. In addition, complex terrain in mountain regions poses a considerable constraint to forest infrastructure and technology (e.g. road networks, harvesting machinery) which reduces adaptive capacities compared to more accessible lowland forests.

³⁶ http://ec.europa.eu/agriculture/fore/events/15-04-2011/report_en.pdf

³⁷ http://ec.europa.eu/environment/forests/pdf/green_paper.pdf

8.6.2 Opportunities

There are significant opportunities in the UK forestry sector to increase the likelihood and effectiveness of adaptation policies and practices. Some of these are discussed briefly below:

1. National low carbon policies (e.g. DECC, 2009a, 2009b), especially in renewable energy and carbon sequestration, and some aimed at protection of soil carbon stocks, leading to new policies and financial drivers to encourage woodland establishment and re-management, whereupon adaptation can be built in.
2. The Woodland Carbon Code³⁸, supporting voluntary carbon sequestration projects that incorporate core principles of good carbon management as part of modern sustainable forest management. This initiative offers opportunities for establishing resilient woodland.
3. Socially, as well as environmentally, driven forestry policies, e.g. in Wales, towards mixed species and LISS and CCF systems, thus potentially building more resilient forests for the future.
4. The potential for the public forest estate in each UK country to act as exemplars of adaptive forest management practice, with designated demonstration forests and research forests to promulgate good practice based on sound science.
5. The UK National Ecosystem Assessment (2011) framework, which places the need for climate change adaptation in the context of a wide range of forest goods and services, and enables better land-use planning which will support adaptation too.
6. Potential reform of the CAP and RDP in 2013³⁹. Opportunities under the EU Rural Development Regulation (RDR) and the Common Agricultural Policy (CAP) Single Payment Schemes need to be exploited more intensively (Silcock and Manley, 2008) to encourage further tree planting on agricultural land. There is renewed interest in agro-forestry, the use of land for combined tree and other cropping or animal husbandry. This would help increase tree cover at the landscape-scale, and improve connectivity between woodlands.
7. Increasing UK woodland establishment and re-management to meet concerns for adequate stocks of timber in context of increasing demand and possible shortage in the face of climate change (Foresight International Dimensions of Climate Change, 2011).
8. Using the opportunity of expanding forestry for wealth creation and rural employment, following particular devolved forestry policies, as a means of establishing resilient woodland.
9. Utilising the publication of the revised UK Forestry Standard (Forestry Commission, 2011d) and associated Guidelines, to give a modernised and future-facing perspective of multifunctional and integrated forestry policy and practice.
10. Adaptation supported by a renewed UK forestry climate change research programme, increasingly linked into other vital programmes

³⁸ <http://www.forestry.gov.uk/carboncode>

³⁹ <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2010:0672:FIN:en:PDF>

such as LWEC and the Scottish Government Centre of expertise in Climate Change.

11. International and EU-wide research programmes on forest adaptation and related forestry science. These are particularly important for climate change, given the exchange of information on future tree material and environmental conditions that occurs.

8.7 Discussion and Conclusions

Compared to several other sectors, forestry seems comparatively well advanced in its preparedness for climate change at an institutional and policy specific level. This is probably helped by the traditional need of the sector to look at timescales measured in decades or centuries in its business and corporate planning processes. In addition, the central tenet of UK forestry, 'Sustainable Forest Management' (Forestry Commission, 2004; 2011d), requires forestry stakeholders to consider the future when managing the present.

Nevertheless, some parts of the sector are more advanced towards effective adaptation than others, and there remain many constraints and barriers which prevent more rapid change. Unmanaged woodland is particularly vulnerable to climate change unless appropriate policies are put in place. However, a number of important drivers for change have been identified, and many of these already exist and are having due influence. This is, in part, because of devolution of forestry policy to Scotland and Wales in 1999, and the subsequent evolution of new policies in all countries which were able to incorporate emerging knowledge and understanding of the likely effects of climate change.

9 Discussion

9.1 Risks from climate change for forestry

Forestry is a sector that relies ultimately on the growth of plants, which is determined directly (e.g. precipitation, solar radiation and temperature) and indirectly (e.g. pests and pathogens, management decisions, technological changes) by climate conditions. The forestry sector is thus sensitive to climate, and indeed, the afforestation programme which has doubled woodland cover over the last 90 years in the UK (see Chapter 1) has depended upon an effective understanding of these relationships. However, the expansion and management of this woodland cover has been based, until recently, upon the assumption of a relatively stable climate. There is now a widespread recognition (see Chapter 8) that the sector needs to understand the likely impacts posed by changes in climate and an assessment of risks resulting from it. Such risks may be detrimental or beneficial. This risk assessment has been carried out through the development of a few example response functions and the application of UKCIP projections to these response functions to assess some important example future risks (see Chapter 3). The response functions have been developed on the basis of published research, data and model outputs and expert judgement. It has been emphasised that there are a number of limitations with each of the response functions so the resulting risk assessments for the future should be treated with caution. There are several important aspects of climate change and forestry that need to be borne in mind when reviewing these assessments, particularly the available evidence base for climate effects and the timescales of forestry.

9.1.1 The evidence base for climate change impacts

While there is clear evidence for the UK of the impacts of recent climate change on woodland composition and function (Broadmeadow *et al.*, 2009a), it is rather limited. In part this is because of the difficulties in disentangling climate change influences from changes in land use and forest management, forest age or other environmental influences such as air pollution, or the introduction of pests and diseases that are not necessarily related to climate change. Furthermore, existing anthropogenic climate change in the UK is small compared to that likely in the future (e.g. only a change in mean temperature of 0.8-1.0 °C so far; Broadmeadow *et al.*, 2009a). Thus while individual extreme periods or events can be used to give some indication, it is difficult to derive with confidence from these limited events quantitative impacts that can be used to derive the response functions required for risk assessment, as described in this report. It is usually the case that there are multiple climatic factors affecting the growth, reproduction and survival of trees, and other components of the woodland ecosystem and it is rare, particularly in temperate ecosystems, that there are single limiting factors. In addition, climatic factors have very different effects at different stages of the lifecycle of trees (Quine *et al.*, 2011).

Although it is usual to consider the effects of climate change on systems, for many natural ecosystems, it is the effects of changes in the weather (the individual events and short-term conditions, such as droughts, frosts, storms) that have the impact, not the overall change in climate (average weather conditions). For example, long-term species composition and woodland structure can be affected by a dry year (e.g. 1976 drought, Lady Park Wood, England-Wales border, Peterken and Mountford, 1996). In addition, sequences of drier years, a run of wetter or colder periods, multiple outbreaks of disease, repeated high or low temperatures can have more impact than single, more

extreme occurrences. Furthermore, weather events occur locally, so it is actually microclimate that matters, not the larger scale macroclimate. Thus, characteristics of the woodland location have a major influence, such as elevation, slope, aspect and soil types. While use of UKCP09 and its probabilistic outputs can assist in assessing some of these risks, the main problem is still the considerable difficulty in assessing the key relationships from the past record of changes and the possible responses, in order to make projections of impacts of future changes.

9.1.2 Forestry timescales and risks

A key difference between forestry and the other main sectors based on plant growth, namely agriculture and horticulture, is the much longer timescale of forestry. Present woodland areas are the result of decades or centuries of previous tree growth and accumulated climatic influences, and future woodlands will be determined by all the past and continuing changes in climate. These can be very short timescale events (e.g. catastrophic wind damage), medium term (e.g. introduction of new pest or disease, such as oak mildew in the early 20th century) or much slower, longer changes (for example, changing seasonality in rainfall). Arguably, forestry is much more at risk from climate change than agriculture or horticulture because of the long lifetimes of trees. Firstly, this increases risk, because the probability of occurrence of particular conditions usually increases with length of time (although clearly this depends on trends in climate). Secondly, the consequences are more serious because of the cumulative nature of tree growth. Only risks to tree-crop horticulture become comparable, although that enterprise typically has a replacement timescale of several years to decades. However, because forest trees are long-lived, they do have more resilience to milder environmental changes than annual species (Kirby *et al.*, 2009). For example, while late spring frost might destroy an annual crop completely, and may cause damage to newly emerged leaves in trees, it is unlikely to cause complete mortality at least in mature trees, only a reduction in growth that year. As Kirby and co-authors pointed out, veteran oak trees in Windsor Great Park started their growth in the Little Ice Age of the 17th century, and have therefore shown substantial tolerance of varying climate conditions, at least so far (Kirby *et al.*, 2009). Furthermore, because of the long-term nature of forestry, the sector already incorporates the practice of managing multiple risks which include those related to weather and climate, such as wind throw, so has some adaptive capacity already (see Chapter 8).

There are many different elements of the forestry sector (Table 9.1). These have very different timescales and consequently different sensitivities to climate and opportunities for adaptation.

Table 9.1 Examples of forestry activities with very different timescales

Activity	Timescale
Commercial production of timber	Several decades to centuries
Woodfuel production from short rotation coppice or forestry	5 years to one or two decades
Production of seedlings in tree nurseries	1-3 years
Processing of timber	Days and weeks
Use of forests for recreation	Hours, days, weeks

While probably all of these activities will be affected by catastrophic events of a few hours such as wind storms, other climate changes on longer timescales would have different effects. For example, forest tree nurseries have timescales of 1-3 years for sourcing and growing seedlings, and can potentially recover from damage or adapt to changes within that span (dependent on economic resources). Wind damage may

result in an immediate loss of timber production because of damaged material, and losses in potential future material supply until the original projected end of rotation, from several years to many decades ahead. Gradual changes in productivity from, e.g. lengthening growing season or increasing soil moisture deficit, would be more readily accommodated. In contrast, recreational forest use may only suffer a relatively short disruption initially if wind throw occurs, as the public attraction of an area may not be greatly altered by loss of particular tree stands, although this is presumably dependent on the spatial scale of damage. Long-term change in forest appearance through modification of species or silvicultural regime may be hardly noticed by many recreational users, although rapid changes to character from management changes may have negative consequences on public perception.

9.1.3 Climate change and woodland ecosystem services

The recent UK National Ecosystem Assessment (UKNEA) (2011) has highlighted the use of an ecosystem services framework for analysing the benefits that the natural environment provides to society and the nation's prosperity (see Chapter 1). The principal types of ecosystem services provided by woodlands identified in the UKNEA are listed in Table 1.3. The risks analysed in the current assessment have only related to a few of these multiple services. It is clear that climate change may impact on all these services, but different impacts would affect the various forestry ecosystem goods and services in different ways, resulting in different risks. For example, forest fires will impact particularly biodiversity, wildlife habitat and carbon sequestration. Drought may affect productivity and thus timber production much more than amenity or recreation provision, but may also affect biodiversity. The UKNEA approach suggests a useful framework for considering the wider impacts of climate change, and some of these are drawn out in the following section. The UKNEA approach will also be useful for future work on risk assessment, which will help in improved evaluation of the costs of climate change and adaptation measures, which has been difficult with the information presently available (Chapter 7).

9.2 Key climate change risks considered in the CCRA

9.2.1 Pests and pathogens

Risks

The incidence of pests and pathogens can sometimes be linked to key climate variables, but it is usually much more difficult to find direct quantitative evidence relating pests and pathogens to forest damage and to climate. This is because for both pests and pathogens, there are multiple factors determining their presence, spread and activity, including: abundance and activity of natural enemies or competitor species, the quantity and state of the host tree and possible other intermediate hosts (Broadmeadow *et al.*, 2009b), the possible influence of human agents of dispersal or control, and the genetic variation of the pest/pathogen. In addition, there may be considerable time lags between original infection or outbreak and the occurrence of damage to the host. These characteristics make it very difficult to model pest or pathogen risk, although in this assessment response functions for the outbreaks of green spruce aphid and red band needle blight (RBNB) (Section 4.2) have been used tentatively to explore the possible scale of problem as climate change accelerates.

More research is necessary before such results can be evaluated and extended to other species.

Thus, evaluating the effects of pest and pathogen response to climate change is extremely difficult given current knowledge. For some cases, information on current distribution and associated climate conditions, known biology and epidemiology, can be used with expert judgement to make some assessment of likely changes in prevalence (Broadmeadow *et al.*, 2009b). In other cases (e.g. *Phytophthora ramorum*), it is difficult to make predictions, and the rapid progress of the diseases and the high mortality is catastrophic, resulting in loss of timber production and many of the other forest ecosystem services. In yet other cases, for example *Elatobium*, the effects are not so severe, resulting in losses of productivity that vary over time (Straw *et al.*, 2011). Furthermore, many pests and pathogen risks are influenced by other climate change impacts such as fire, drought and waterlogging that may change the host susceptibility or change conditions for the organism itself (e.g. presence of dead trees providing infection points).

The preliminary risk assessments for RBNB and *Elatobium* exemplify the significant research required to develop future risk assessments. In addition, such assessments need to consider the consequences of outbreaks of pests and pathogens (and conversely, any instances of decline in occurrence), on the full range of ecosystem services – for example, effects on carbon sequestration.

The visibility of pests and pathogen impacts is an additional factor to consider in assessing their consequences. Conditions affecting amenity trees in parks, streets and recreation areas are highly visible, compared to those in woodlands and forests. In addition, there are risks from failure to act and/or mismanagement, especially when iconic tree species are under threat. This may result in additional consequences for owners or those with management and health and safety responsibilities (e.g. horse chestnut leaf miner and bleeding canker, and oak processionary moth).

Adaptation possibilities

Once established, the extent and size of forests, their longevity and often remote locations and the wide range of ownership, implies that for many pests and pathogens there are limited control measures available, particularly at site-level. Some changes in silvicultural practices can be used (for example, tree spacing and chemical application are being examined as a control for RBNB) in addition to regulatory restrictions on infected planting stock. However, the primary mechanism for adaptation will be regional and landscape-level, for example, formation of pest management groups, eradication measures or movement restrictions (Kirby *et al.*, 2009).

Adaptation measures for increased pest and pathogen risk may appear to be limited, and might be viewed as requiring very specific actions for each organism. It will therefore be difficult to generalise adaptation measures and any cost estimates resulting will have huge uncertainty. However, some general principles for adaptation have been proposed (see, e.g. Kirby *et al.*, 2009) and those based on creating resistance and promoting resilience to change, and monitoring change are relevant for pest and pathogen risk. Creating resistance to change ‘buys more time’ for other adaptation measures, so that (for example) reducing rates of spread or intensity of outbreaks will allow more time for replacement with less susceptible tree species. Reducing other stresses may also delay infection or infestation and create resistance to change (e.g. reducing waterlogging through improved drainage, or for amenity trees, reducing drought stress by irrigation). Measures that promote resilience to change have been suggested (Kirby *et al.*, 2009) which may help to reduce pest and pathogen risk are: greater tree genetic diversity (multiple species, and/or a range of provenances); promoting regeneration, to allow more potential for selective pressures

to work; and contingency planning for outbreaks. Monitoring change can help to assess severity of outbreaks and changing trends, and provide evidence of what measures work (Kirby *et al.*, 2009).

9.2.2 Drought damage and loss of productivity

Risks

There is good evidence that key climate variables that result in drought are already changing, as there have been declines in summer rainfall and increases in temperature (Jenkins *et al.*, 2009). Unsurprisingly, forestry stakeholders rated drought an important risk to consider, which guided the development of a risk metric (FO2) relating stand defoliation measurements to soil dryness (PSMD or 'aridity') and to yield losses (Section 4.3). Drought risk therefore will impact on the provisioning services of timber and woodfuel production. 'Drought risk' *per se* is one extreme of a continuum of impact resulting from the combined effects of reduced rainfall particularly in summer and higher temperatures to cause reductions in soil water availability. While prolonged periods of dry soil and high evaporative demand cause drought stress and can cause damage to tree growth, defoliation (see Section 4.3) and even tree mortality, significant reductions in tree growth and therefore yield may occur with much smaller soil water deficits than those that cause visible damage (see Section 3.2.2). Thus, for many UK woodlands, particularly those on well-drained soils and in the warmer south and drier east of the country, periods of drier soil conditions are likely to cause reductions in growth. While small reductions in growth for fast growing softwood species may increase timber quality, it is likely that increased drought occurrence will generally be detrimental. The probability of drought occurrence can be assessed from climate projections using the key drivers of temperature, solar radiation, humidity, wind speed and rainfall, but it also needs information or assumptions about soil water holding capacity and sensitivity of different tree species. The ESC software tool can combine this climate, soil and species information to estimate impacts on yield and species suitability (see Section 5.3), although there are presently limited data on which to build strong quantitative relationships between yield and soil moisture availability, and thus to assess risk to yield.

However, there are several other aspects of drought risk under climate change. For trees, severe drought (either longer periods, or lower soil water contents, or repeated periods) may cause additional risks through insect and pathogen attack on weakened trees (Broadmeadow *et al.*, 2009b). This may be more of a problem for veteran trees, of which the UK has a high density (Kirby *et al.*, 2009). These type of effects have not been included in the risk metrics considered here, and it will be difficult to do so, given the multiple factors and uncertainties underlying such observations. Also, the differing risks of dry soil conditions for trees at different stages in the life cycle are not considered, although it is well-known that tree establishment after planting is very prone to losses in dry conditions.

Drought also affects a wider set of ecosystem services than timber or woodfuel provision alone, for example on ground flora productivity and species composition and the associated fauna. Drought may affect soil processes and, by changing soil water regime and soil water chemistry, may affect water supply and purification services. Drought risk also links to fire risk (Section 3.2.9). Drought would probably have little impact on provision of the woodland cultural services at least in the medium term, although over the long term, it is likely that in the south and east of the country woodland character will be quite different, for example, more open and grassy (Kirby *et al.*, 2009).

Adaptation possibilities

The relative susceptibility of different tree species to drought is reasonably well understood and has been summarised in the Ecological Site Classification (ESC) (Pyatt *et al.*, 2001). Such knowledge can be used with UKCIP projections to support adaptation towards planting of more drought tolerant tree species, although clearly this is a medium to long-term adaptive measure. Furthermore, current restocking rates in the UK are very small compared to the forest area that is likely to require a change of species. There may also be silvicultural measures, such as wider tree spacing that may be helpful. Adaptive measures against drought risk specifically for semi-natural woodlands are very limited (see Kirby *et al.*, 2009). For high value amenity trees, introduction of irrigation or watering regimes may be a feasible adaptation measure, and it may also be necessary to consider watering for some woodland tree planting, to ensure establishment.

9.2.3 Change in tree species suitability and productivity

Risk

There is evidence from several areas in Europe that tree growth and forest productivity has increased recently (e.g. Spieker *et al.*, 1996), and this has been attributed to climate change. However, the causes have been debated, and changes in management and/or availability of nitrogen or recovery from air pollution have also been suggested (Kahle *et al.*, 2008; Broadmeadow *et al.*, 2009a). There is no such unequivocal evidence for changes in tree growth in the UK. Much is known about tree physiology (particularly for key commercial species) so that the detail of the response of trees to climatic conditions can be assessed reasonably well. Indeed, process models of key tree functions are well advanced, although their use for quantitative risk assessment is only just starting, and they lack detailed evaluation against different species and genotypes. It is clear that in some areas, particularly those that are presently cooler and wetter, one consequence of climate change may be higher yields from longer growing seasons, although the long-term duration of such benefits is uncertain. In other areas, water limitation and possibly factors such as lack of winter chilling (required for subsequent bud-break and flowering in some species) may alter species suitability. Interestingly, studies in France have shown increased growth in the northern part of species distributions, but reductions in the southern part of the range (Ciais *et al.*, 2010), which agrees with such generalised predictions.

Comparative information on the growth and characteristics of many different tree species has been compiled, and can be used to inform expert systems (e.g. ESC) for prediction of tree species suitability with different climate change projections. Such tools can assess climate change risk at local and regional scales (Sections 4.4 and 5.4), although their resolution is limited by soils and microclimate information. Furthermore, they are presently limited in the information they have on the suitability of different tree provenances. In addition, such tools do not presently take into account susceptibility to pests and pathogens, and their yield impacts, and do not take into account the likely growth increases with increased CO₂ (see Section 3.2.11). Yield is also only assessed in volume terms, not on quality or end uses.

The impact of climate change on tree species suitability will also depend on socio-economic drivers, such as the extent of global timber trade, changed international supply and demand, or changing importance put on timber security and local production (Chapter 6). Such changes may put a higher weighting on more productivity species, or their suitability for particular end uses. This may then impact

on the processing sector, and require changes to machinery and affect investment decisions.

Adaptation possibilities

If species suitability changes because of climate change, species change might be possible as an adaptation measure. Substitution of tree species might be radical (e.g. native broadleaves for non-native conifers) or conservative (change of pine species). Depending on the extent (both in area and in character) of the tree species change, the broader biota will respond accordingly. Radical change in tree species is bound to change the overall nature and diversity of (new) woodland fauna and flora, and is therefore likely to impact on multiple ecosystem services (Table 1.3).

Changing tree species is a medium- to long-term adaptive measure. Clearly, for short rotation plantations, such as much of the productive conifer, replacement could be considered within a maximum of 40-50 years, and given the current age profile of much of the conifer resource (Figure 1.2), much could be achieved earlier. However, the analysis of the climate change projections for the upland areas in the north and west of the UK where these plantations are concentrated indicates that there is less urgent need for change. Broadleaved species in the south and east of the UK pose much more of a problem, given the long rotation timescales coupled to more rapid change of suitability. In addition to these questions of timing, the pest and pathogen vulnerability will need to be assessed. In semi-natural woodlands the options for species change are much more limited, and will depend upon rates of species spread. Key questions for adaptation will be about how long the current species should be maintained, and whether dispersal processes should be assisted (Kirby *et al.*, 2009). Species change may also impact on the cultural services, if introduction of new non-native species are planned as components of new woodlands, or during restocking (e.g. use of *Eucalyptus* species).

9.2.4 Forest fires

Risks

It is likely that the drier, warmer spring and summer conditions projected for many parts of the UK would increase the probability of wildfire outbreaks. This is in line with some evidence that an increase is already occurring (e.g. Broadmeadow *et al.*, 2009a). Given the present rate of climate change, and the existing relatively low incidence compared to continental and Mediterranean countries, forest fires may not become a serious problem until the 2050s onwards (Section 5.5). Although large-scale fires are unlikely given the fragmented nature of UK woodlands, any forest fires are likely to cause substantial loss of local ecosystem services, particularly biodiversity, carbon sequestration, recreational and other cultural services. Several major impacts of forest fires occur outside the forest, for example in subsequent polluted runoff into reservoirs, and to transport and other infrastructure running through and adjacent to forest areas. These may be more costly than the actual losses of forest ecosystem services, so there are cross-sectoral implications of a change in forest fire risk.

Grassland fires are presently the most common wildfire in the UK. These are usually started through human activity, and while they are unlikely to spread into mature deciduous woodland, they are particularly likely to cause destruction of newly planted woodland areas, and conifer plantations in thicket stage with consequent large opportunity losses. Damage to veteran trees, especially those in parkland settings, may also be a particular concern (Kirby *et al.*, 2009). Woodland areas particularly at risk are urban and peri-urban woodlands, where there are frequently a mix of

vegetation types, including those providing high potential fuel loads, high human visitor pressure and consequently a high probability of fire starting, either deliberately or accidentally. In exactly these areas the economic costs may be largest from damage to property and disruption to communities (e.g. Swinley forest fire, Berkshire, 2011), or loss of visitor revenue, and substantial resource required to manage and combat. Woodland areas at visitor attractions are also at high risk, for similar reasons, and because of the consequence of fires for visitor revenue. Furthermore, fires are an emotive and highly visible destructive event, so there is a high reputational risk for woodland owners and managers if fire risk is not controlled at low levels.

Adaptation possibilities

There are adaptation possibilities for managing risk of forest fires. For forest managers there may be opportunities through redesigning forest areas with different species, tree stand types, layout and vegetation management. Introducing such measures at the appropriate stage in the forest management cycle such as after felling or at restocking will probably be the least costly option, if there is time to do so before the risk becomes too large. Fire risk reduction through altering vegetation types or management may, however, conflict with provision of other services, such as biodiversity. Conversely, other measures introduced in part to improve climate change resilience may increase fire risk. For example, cohorts of young trees regenerating after introduction of continuous cover forestry management may reduce fire probability but increase damage to the main crown layer if fires occur (Stokes and Kerr, 2009). There are also options (and costs) to increase fire prevention and control measures (e.g. reservoirs), to reduce risk that can be carried out in the short term. However, fire risk management is outside the complete control of forest managers, and adaptation measures will require joint initiatives with other stakeholders involved in land use management, for example, those in wildlife and habitat management and civil emergencies.

9.3 Adapting in the face of other impacts

As well as the impacts explored using risk metrics and response functions, the risk to other important forestry ecosystem services are briefly discussed below.

9.3.1 Impacts of climate change on biodiversity

The recent UKNEA report makes clear that the biodiversity present in UK woodlands and forests can be viewed as providing several ecosystem services (Quine *et al.*, 2011). It is a supporting service (Table 1.3), with diversity of species and organisms contributing to essential ecosystem processes such as provision of biogeochemical cycling, dynamics of vegetation and woodland regeneration. But biodiversity is also often a woodland management objective requiring time and effort to provide particular types of diversity and species assemblages. Thus it can be also considered a provisioning service and the costs of such management and their benefits can be monetised (Quine *et al.*, 2011). Woodland biodiversity can also be considered a cultural service, as particular species or assemblages are what are valued by visitors (Forestry Commission, 2009b) or by members of woodland conservation organisations. All the major climate change risks are likely to alter biodiversity in some way – maintenance of exact locations, assemblages and relationships between fauna and flora will not be possible given the climatic effect on species autecology (Chapter 3). There would be inevitable losses of some species as habitats change, but some increases caused by arrival of new species, some of which may be judged ‘non-native’.

Adaptation policy in support of maintaining woodland biodiversity must therefore be framed using best available scientific understanding. A species-based approach to nature conservation will be difficult to maintain in the long term because of the likely degree of change (Chapter 3). The Ecosystem Services framework (UKNEA, 2011) may provide a mechanism to explore and prioritise decisions about managing woodland biodiversity in the future, especially as these objectives will need to be placed objectively amongst many others, including relatively new ones such as carbon sequestration.

9.3.2 Impacts of climate change on amenity values

Woodlands and forests provide very significant cultural services (Edwards *et al.*, 2009; Quine *et al.*, 2011). Forests and woodlands are highly appreciated by people for their historic and cultural characters, and as places for recreation. There are 250-300 million visitors to British forests each year, many undertaking physical activity, resulting in considerable mental and physical health benefits (Quine *et al.*, 2011). Forests and woodland can provide a focus for community activities that promotes cohesion, and there are many informal and formal educational opportunities. Forests can have significant aesthetic appeal, and can enhance landscape character, as well as form a wide range of subjects for the various arts. Many different aspects of climate change may alter the nature and characteristics of woodlands, which may affect their cultural and amenity values, but it is uncertain and difficult to assess how attitudes will change. If conditions are warmer and drier, the shade of forests and urban woodlands may well be more attractive, but it is difficult to assess risks as there are likely to be strong socio-economic drivers influencing visitor patterns, including access rights, costs of transport, rates of urbanisation and amounts of leisure time (Chapter 6). In some countries there is good evidence that certain types of visitors to forests are prone to develop tick-borne diseases such as Lyme disease (e.g. Vanwambeke *et al.*, 2010) and there is some evidence that recent climate change has increased tick populations and therefore the risk of visitors contracting disease (Lindgren, 1998; Lindgren and Gustafson, 2001) though the quality of evidence for this is contested (Randolph, 2004; 2010). Nevertheless, there is increasing empirical evidence that identifies an association between tick phenology and climate (Gatewood *et al.*, 2009) and that the risk of tick-borne disease could increase with projected changes in climate. This could have a significant effect on visitor attitudes, numbers and enjoyment and benefits derived.

Importantly, it is likely that many adaptive measures in forestry management will increase amenity value – for example, diversification of tree species, stand management and harvesting regimes without clearfelling. However, some climate change responses and adaptive measures may reduce cultural services – for example, forest closure because of fire risks, wind storm damage or biosecurity measures, the use of fast growing exotic species for woody biomass production, or less open areas to increase forest carbon sequestration or productivity.

9.4 Broader implications for adaptation in the forestry sector

The long timescales of tree growth and consequently woodland management and the likely speed of climate change mean that some adaptation decisions need to be taken now, especially for regions of the UK where climate change projections indicate most rapid change (e.g. south and east England). For other regions, it is possible to consider one further rotation of the existing tree species before they need to be changed to be better suited to the new climate, or other silvicultural adaptation is

necessary. Clearly, in making many adaptation decisions such as adopting new species or provenances there are substantial risks, but timescales are now far too short to test with the conventional approach of species research trials followed by operational trials. Therefore, adaptation measures will need to accommodate change and uncertainty, which makes a strong case for adaptive forest management, as a formalised process of assessing questions, planning changes, monitoring results and modifying practice (Helms, 1998; Raison, 2002; Lawrence and Gillett, 2011).

While this risk assessment has considered primarily examples of direct climate change impacts and risks, climate change is also driving other changes in forestry, particularly around climate change mitigation and the demands for the sector to contribute to the low carbon economy. Forests provide the key service of carbon sequestration, and projections of the decreased carbon sink likely because of the age profile of UK forests, coupled to the need for increased sequestration to offset emissions means that there is great urgency in initiating measures to increase woodland creation rates (e.g. Read *et al.*, 2009). The recently published 3rd progress report of the UK Committee on Climate Change (June 2011) emphasised that a comprehensive woodland creation plan would be needed to establish 21,000 ha of woodland each year to deliver an additional annual abatement of 1 Mt CO₂ year⁻¹ by 2030. Such woodland creation activities will need to assess the risks from climate change, and the requirement for adaptation measures.

Furthermore, forestry is required to make a substantial contribution to renewable energy production through the increase of woodfuel provision, particularly from presently under-managed woodlands, but also newly established short-rotation forest. Forestry Commission England has recently published the Woodfuel Implementation Plan as part of the National Renewable Energy Action Plan – a requirement of the EU Renewable Energy Directive (Forestry Commission England, 2011b). This implementation plan will also provide the platform from which to encourage a greater uptake of the new English Woodland Grant Scheme – Wood fuel Woodland Improvement Grant that was also launched in summer 2011. The grant aims to create the infrastructure (forest roads etc.) to improve access to / from woodlands for greater timber production for the woodfuel market. Both these initiatives, which are responses to climate change, will have substantial impacts on the management of UK woodlands and forests, and help to provide further opportunities for adaptation.

Some country forestry strategies already encourage changes in practices that will act to increase adaptive capacity. For example, the diversification of species and forest management systems in Wales for landscape and biodiversity objectives will also act as an adaptive measure to reduce climate change risks. Adaptation to reduce other risks may mean trade-offs against other ecosystem services. For example, lowering tree stocking densities to reduce risk of pathogen outbreak (e.g. with RBNB) will reduce productivity. Similarly, harvest before normal age or size to reduce the risk of wind throw will lose production opportunity.

Recent work initiated by the Forestry Commission has been important in producing information, tools and instruments to help the sector adapt according to current knowledge (e.g. Read *et al.*, 2009). These include Forests and Climate Change Guidelines for the UKFS, the Forestry Commission England and Forestry Commission Scotland Climate Action Plans, and country-specific Forestry Commission Research Notes on climate change impacts.

9.5 Strengths and weaknesses of the present risk assessment

The risk analyses described here, despite inevitable limitations, have indicated possible scales of impact on forestry associated with important risks as climate change occurs. This work represents novel and useful ways forward, which will need to be further developed over the next few years, for ongoing adaptation planning, and also specifically for the next round of the CCRA. The report has focused around nine main climate change impacts (Table 3.2), and worked on a detailed analysis of four risk metrics. These risks arose from expert consultation, but it should be recognised that other risks may emerge as experience of climate change builds in the forestry sector, or as changing socio-economic drivers creates or suggests different exposures.

Many of the difficulties and uncertainties with the nine specific impacts considered in this report, and with the detailed risk analyses carried out, have been discussed earlier in this and other chapters. For the four risk metrics used in Tier 2, Table 9.2 summarises some key limitations and suggests how they can be addressed in the future. Some additional general points need to be recognised about the work in this assessment:

- Most response functions used are based on only one climatic variable which oversimplify the complexity of dependencies. Most biological systems respond to a host of climatic signals and drivers. Therefore, there is a large uncertainty built into the existing projections.
- Climate is only one of many drivers for change in the forestry sector. It is therefore difficult to separate the effects of likely climate change from other drivers that currently impinge on forestry, and difficult to identify from existing evidence of change what the drivers are. However, the CCRA approach here has recognised the key different drivers, even though it is not presently able to integrate them. Future work will need to develop analyses that combine multiple types of impacts into risk assessments.

The response functions used were built for a limited set of risk metrics. The work provides an overview of the potential main climate change impacts and more detailed studies are necessary to provide more information on the scale and nature of consequences.

9.6 Gaps in evidence

The following are considered some of the most important issues for which there is currently inadequate knowledge in order to progress adaptation in the forestry sector. Research priorities across topics related to understanding climate change and forestry were published recently (Read *et al.*, 2009):

- Better knowledge of how different tree species and provenances will respond to climate change, and information on how their populations and distributions are already changing.
- Information on how forest disturbance regimes will change (e.g. wind throw, fires).
- More understanding of how to improve resilience at landscape scale (including the woodland component), and its economic benefits.

- Quantifying/understanding the spatial and dynamic nature of ecosystem goods and services, and their responses to climate change.
- The development of scientifically robust tools for identification and optimisation of land types and areas suitable for expansion of particular woodland types in the face of climate change.
- Better understanding of societal and stakeholder motives and incentives likely to help overcome barriers to adaptation.
- The need to pilot operational scale adaptive forest management, with scientifically rigorous monitoring and evaluation linked to planning and decision making.
- Progress in assessing the likely impacts of extreme climatic effects on woodland function and ecosystem service provision.
- Modelling of impacts of climate change and possible adaptation measures on forest and carbon inventory and production forecasting.
- Improved woodland surveillance and enhanced early detection of possible impacts of climate change, at a range of scales.
- Better understanding of risks posed by current and possible future insect pests and pathogens to British forests, woodlands and trees, including modelling of future outbreaks under a changing climate.

Table 9.2 Confidence, limitations and recommended improvements to Forestry Tier 2 Risk Metrics

Metric	Descriptor	Confidence rating⁴⁰	Derivation and key limitations	Ways to improve confidence
FO1	Forest extent affected by pests and pathogens	Medium	Based on exploration of possible biological response of one example pest and pathogen using a single climate variable for each to build a response function. Very limited evidence to establish response functions, little generality for other pests and pathogens.	Modelling for a wider range of damaging pests and pathogens, using more complex models (such as CLIMEX) where these exist, or developing them where this is possible. Targeting examples from a range of types of organisms, with different climate driver sensitivity. Coupling these models with actual or modelled location of forest tree species in future decades, and with relationships between pest and pathogen prevalence and effect on tree growth.
FO2	Loss of productivity due to drought	Medium	Based on relationship between aridity/soil moisture deficit and defoliation severity as an indicator of stress, and assumed link with yield. Relies on weak correlation of general regional crown condition data with specific soil moisture deficit.	Evaluating risk using process models which describe more precisely reductions in tree growth and yield response to modelled soil moisture deficit, using climate projections and soil information. Using separate analyses to evaluate damage from severe drought (timber quality, pest and pathogen risk etc). Coupling these models with actual or modelled location of forest tree species in future decades.
FO4	Change in tree productivity	Medium	Based on Forest Research's Ecological Site Classification expert system, which allows empirical modelling of forest productivity in relation to several climate variables (moisture deficit, accumulated temperature, windiness) and soil type.	Extending ESC approach to all of UK forest area using information from the National Forest Inventory. More evidence on productivity of new species, and productivity of semi-natural mixed woodlands. Building the likely effects of changing climate, (including increased atmospheric CO ₂ concentrations) into forest production forecasting. Combining productivity change modelling with analysis of extreme event probability (e.g. wind throw, frost, fire, pest attack).
BD12	Increased risk of wildfire	Medium	Based on novel application of McArthur Forest Fire Danger Index. Risk assessed on average annual change only, no seasonality effects. Not developed for UK fire conditions and forest types.	A new look at forest fire risk assessment for the UK is required, building on relevant international experience, but developed for UK forests and climate conditions, evaluated with existing UK data, using detailed UKCP09 climate projections, forest area data from the National Forest Inventory, and soil data.

⁴⁰ Definition of confidence can be found in Appendix 4

10 Conclusions

The forestry sector may be significantly affected by climate change over most parts of the UK, and the range and nature of goods and services provided by them may also change considerably. The likely range of impacts has been identified with reasonable confidence. Most of the impacts discussed have negative consequences, but there are also some opportunities for the sector, including an increase in productivity in some areas.

The substantial risks from pests and pathogens are likely to increase with projected climate change, although they are currently difficult to quantify. Increasing drought is also likely to be a major driver of woodland change. Non-climate related drivers (such as timber trade, land use change, renewable energy demand, socio-economic development, population growth etc.) are also expected to have a major impact on the future of UK forestry and the risks from climate change must be considered in this broader context.

The CCRA has been valuable in identifying the main risks to the forestry sector, and identifying where further action is required. There is reasonable confidence in the qualitative identification of the key impacts. Much research addressing climate change risks and adaptation measures is presently underway. Further research is essential to improve the precision of understanding and quantification of these risks and their environmental, social and economic consequences. However, as climate changes further and impacts are more widely felt, other impacts may be identified, and their relative importance may well change.

The forestry sector has a reasonable understanding of the risks currently identified and is relatively well prepared to mitigate many of the risks of climate change. Forestry's long-term nature means that the sector has had to prepare plans in order to remain sustainable, and this covers the time-scale being examined under the CCRA. In the management of the public forest estate the adoption of adaptive forest management as a key response is being actively considered. In privately owned forests and woodland, which comprises a spectrum of owners and scales from large-scale commercial enterprises to the many small-scale private owners, it is presently hard to assess adaptive capacity.

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Appendices

Appendix 1 Consultation Feedback

Consultation was carried out in Tier 2 to review the list of impacts (Table A1.1), consequences and possible risk metrics (Table A1.2) identified from Tier 1 and identify additional impacts and risk metrics. The standard approach for this step in the CCRA was to carry out consultation through an expert workshop. For the forestry sector, however, the consultation was carried out by individual telephone interviews with fourteen experts drawn from across the sector. A summary of the results of this consultation are presented below. Full details can be found in Moffat and Morison, (2010).

1.1 Sector impacts

There was a broad understanding by interviewees of the approach adopted in selecting impacts, and discussion mainly dwelt upon missing impacts perceived as important by the particular respondent. However, the documentation on impacts also generated some interesting additional views and a range of additional impacts was put forward. To an extent, they appear to reflect the particular issues faced by the respondent and their organisation, whether at a geographical or discipline-based level. Nevertheless, these points reinforced the view that the sector spans a very wide interest base, and that it is easy to ignore or forget impacts that cause others concern. Some issues were national in likely effect, but others were more specific and localised, such as freeze-thaw impact on forest roads. For these it is difficult to judge whether the size of impact is likely to be of a similar magnitude at a national scale. Some impacts suggested were somewhat indirect and more conjectural, although established in current scientific understanding to some degree.

Some interviewees raised the possibility of impacts based around adaptation activities in the forestry and other land-use sectors. For example, competition for land and the possible need to grow more food nationally may impact on woodlands and the desire to see woodland area expand. Similarly, others raised concerns about the impact of novel tree species, planted as an adaptation measure, on woodland biodiversity. Such impacts may be driven by a change in climate, but it would be extremely difficult, if not impossible, to attribute to specific elements of the climate. The point that impacts could be positive as well as negative was raised by more than one respondent.

Several correspondents considered that scale and the limits to the forestry 'system' are important issues when considering the comparative degree of impact that those listed might exert. There was a danger that by undertaking analysis based on a catalogue of simple reducible impacts that more complex impacts, both positive and negative, might be missed. Scale, too, could get in the way of reaching an effective understanding of comparative impact effect, and prioritisation of risk for the sector as a whole.

As well as comments about the list of proposed impacts and their nature, some interviewees sought to comment on the CCRA process, the methodology of pedigree and confidence scoring, and the method of grouping impacts into broad categories. Such comments were expected, and helpful, but were only a few in number.

1.2 Prioritisation of impacts

Discussion on this subject was based on interviewee expertise, rather than on an analysis based on the CCRA methodology (i.e. on scoring for magnitude, urgency and likelihood) (Defra, 2010). To a similar extent as in the identification of missing impacts, choice of priority impacts was sometimes explicable because of the particular business that the sector representative was involved in. The topicality of other impacts, e.g. the importance of pests and pathogens, might have also had some influence on how it was

regarded during this evidence gathering process. Nevertheless, there emerged some broad agreements that this potential impact, together with that of drought, were regarded as perhaps the most important. The impact on biodiversity and/or woodland habitat was also frequently mentioned. Extreme weather events, such as storminess, or consequences such as flooding, were considered important by some. Some impacts raised as of particular importance in Tier 1, such as forest fires and change in the growing season, were largely ignored during the telephone interviews. It is difficult to know whether this means there was broad acceptance about the importance of these impacts or not. As before, some useful additional comments were made about impact prioritisation. Some felt it an almost impossible task, given that climate change is not 'linear', whilst the problem of different scales involved for different stakeholders was mentioned by others. Uncertainty, presumably both in climate projection and in possible outcome(s), was also brought up. One respondent made the point that the indirect effects of climate change may be more important than some of the climatically driven ones, notably for adaptation policy to react effectively.

1.3 Risk metrics

Respondents offered a long list of additional risk metrics, in addition to sometimes critical commentary on those offered in the introductory material. Some suggestions were for metrics that could operate at a national scale, whilst others again seemed to serve the particular interests of the respondent. Some specific measurements were advanced instead of metrics as defined in the CCRA Method Statement (Defra, 2010). Many contributions were at the level of suggesting a metric was required for a particular aspect of the forest ecosystem likely to respond to climate change, but without suggesting what the metric might be. Where some specific metrics were suggested, it was rarely the case that they could be harnessed for further study because of lack of available data. Scale again emerged as an issue, with some metrics more suitable for local or specific parts of the forest ecosystem.

Comments on the list of metrics sent out in advance of the interviews were helpful. In general, it seemed that most respondents were supportive of those metrics related to forest productivity – or could more readily see the relationship between tree and forest growth and climate change. Some metrics, such as the number of SSSI's in good condition, were rejected, probably because interviewees saw them as focussing on the unusual and specific scientifically-rich features of woodland rather than representing the broader wildlife habitat that woodlands form.

1.4 Synthesis

The formal process of interacting with representatives across the forestry sector was informative for several reasons. Firstly, responses reminded us of the wide range of concerns that respondents have about climate change. They also helped to see beyond the likely biological impacts into the complex ways in which impacts might be felt in parts of the ecosystem, and on the goods and services that woodlands and forests currently supply. They ensured that further risk analysis does not focus solely on the conventional or traditional aspects of the forestry industry, namely timber production.

Secondly, interaction helped authenticate, for the most part, the approach adopted so far. Many suggestions were made for additional impacts and risk metrics, and in analysing their relevance and usefulness, further refinement was made to both lists. It was not possible to include every suggestion – some seemed to fit the needs of the Risk Assessment project better than others.

Thirdly, the combined testimony of the respondents is an invaluable 'pen picture' of forestry in 2010, and may be useful beyond CCRA 2012. For example, the

prioritisation of impacts can be seen as an inevitable product of current, as well as predicted future times. Focus on pests and pathogens for instance, has probably been caused in part by the large number of damaging outbreaks in recent years, and the publicity that they have received. In addition, the recently published 'Read Report' (Read *et al.*, 2009) has done much to publicise likely impacts that are likely to be important to consider in any adaptation strategy, and this probably influenced respondents.

Without such evidence, such a process would have been reasonably regarded by some as very subjective – though it remains important for decisions made to be further peer reviewed.

1.5 Conclusions

- A number of potential impacts that were not identified in Tier 1 were highlighted by consultees.
- Adaptation to climate change in the forestry sector (in terms of the ways in which forests are managed, for example taking into consideration tree species selection as well as planting and felling practice) is likely to have a major impact on the nature of woodlands (as this would affect woodland type, structure, biodiversity etc).
- There were concerns raised over the limitations with analysing the impact of climate change on forestry with a response function approach that reduces interactions to a few variables.
- There was broad agreement with the importance of the selected impacts and risk metrics for the Tier 2 analysis, but no specific comments regarding the scoring of impacts.
- Many consultees raised the potential impact of pests and diseases, and drought, as two of the most significant likely effects of climate change.
- The impact of climate change on biodiversity and woodland habitat was also seen as important.
- Indirect effects of climate change (e.g. adaptation) may be more significant than the change of climate itself.

Table A1.1 Tier 1 impacts for the forestry sector

Climate effects	Impacts	T/O/N [*]	Direct Consequences	# Pedigree	# Level of confidence
<i>Main climate driver: Increase in carbon dioxide levels</i>					
Increased CO ₂ concentration, longer growing season	Increase in productivity of some species e.g. for biomass production		Increased timber supply	3	# H
Increase in CO ₂ concentration	Denser canopies		Reduction in light levels on forest floor and ground vegetation and community structure; ephemeral/weed species may benefit at expense of slower growing species	1	# M
Increase in CO ₂ concentration as well as changes to temperature and precipitation levels.	Changes in soil organic carbon		Change in soil nutrient levels and water availability impacting ecosystem functioning		# M
<i>Main climate driver: Changes in annual, seasonal or extreme precipitation</i>					
Drought / successive droughts	Serious damage to trees for example stem increment of beech; serious damage to tree stands		Reduced high-quality timber supply; trees more susceptible to disease	2	# M
Drier summers (decrease in summer rainfall)	Oxidation of peatlands			2	# M
Droughty conditions - increase in average temperature; wind	Increase in grass and forest fires / increased fire fighting		Tree damage; increased tree vulnerability to insect attack; risk of soil erosion and water pollution	2	# L
Reduced snowfall	Decrease in snow damage (although the remaining snow may be 'wetter' and cause more damage			1	# H
# Decrease in summer rainfall	Drought during period of woody growth		Reduced tree growth	1	# M
Spring and summer drought	Newly planted trees threatened		Reduced tree growth	1	# M
Increase in frequency of extreme rainfall events	Increase in localised flooding, channel scour, soil erosion and landslipping		Tree damage; disruption to local infrastructure, communities and businesses	1	# M
Increased winter rainfall	Water tables raised enough to kill tree roots		Reduces effective rooting depth and makes trees more vulnerable to summer droughts	1	# M
Increased winter rainfall	Waterlogging of soils		Limited access for machinery to avoid damage to the soil; reduced stability potentially limiting rooting depth and making some	1	# M

Climate effects	Impacts	T/O/N*	Direct Consequences	# Pedigree	# Level of confidence
			species more vulnerable to summer drought		
Decrease in summer rainfall	Limits the current range of tree species that can be grown on droughty soils			1	# M
<i>Main climate driver: Extreme weather events (precipitation and temperature)</i>					
Reduced soil moisture	Changes in species suitability			2	# M
Increased frequency of high or extreme temperature episodes / particularly droughts	Damaging effects of pests exacerbated		Tree damage;	2	# M
More extreme weather events	Migration of tree species/loss of native tree species in southern England		Biodiversity and habitat loss; possible threat to important woodland species	2	# L
Changes in temperature, rainfall and frequency of extreme weather events	Biodiversity loss		Biodiversity and habitat loss; possible threat to important woodland species	1	# M
More extreme weather events	Potential reduction in some of the damaging effects of pests		Reduced tree damage	1	# L
<i>Main climate driver: Sea-level rise</i>					
Sea-level rise	Loss of habitat (although very little woodland at risk from saline incursion)			2	# H
<i>Main climate driver: Changes in annual, seasonal or extreme temperature</i>					
# Temperature / precipitation changes	Increase in 'weed' species		Rank vegetation that competes with young crop trees and non crop (native) species will result in greater mortality of young trees through aggressive competition	3	# M
Increase in average winter temperature	Winter chilling requirements for flowering or seed germination not met		Reduced natural regeneration	2	# H
Increase in average temperature (high temperatures)	Increase in emission of volatile organic compounds from trees		Decline in air quality	2	# M
Higher earlier spring temperatures	Earlier budburst leading to increased damage by late frosts		Reduced high-quality timber supply; crop damage	1	# H
Warmer winters (increase in average winter temperature)	Reduction in winter cold damage (although reduced)			1	# H

Climate effects	Impacts	T/O/N*	Direct Consequences	# Pedigree	# Level of confidence
	hardening could reverse this benefit)				
Warmer winters (increase in average winter temperature)	Reduction in cold-associated mortality of insect pest, deer and squirrel populations		# Tree damage	1	# H
Warmer winters (increase in average winter temperature)	Potential for range of new species			1	# H
Increase in average winter temperature	Increase in delayed or incomplete winter hardening		More serious winter tree damage	1	# M
Increase in average temperature; increased rainfall in spring and summer	Increase in pests and disease and activity		Tree damage	1	# L
Increase in average temperatures	Increase in invasive flora and fauna		Loss/damage of trees	2	# M
Increase in summer temperatures	Increase in tourism numbers			1	# M
<i>Main climate driver: Changes in extreme wind events</i>					
Increase in storm events	Catastrophic wind throw		Reduced high-quality timber supply; loss of recreational areas; loss of habitat	3	# L
Change in storminess	Loss of mature woodland habitat		Benefits associated with opening canopy enhancing regeneration	2	# L
<i>Main climate driver: Seasonal changes</i>					
Lengthening growing season, wetter winter conditions	Possible reduction in the window for lifting nursery stock			1	# M

*T= threat (red), O = opportunity (green); N = neutral impact (amber)

Table A1.2 Tier 1 Risk Metrics

a) Productivity
• Areal production (m ³ or green tonnes per hectare)
• Area affected by wind throw/wind snap (ha)
• Area affected by forest fire/number of forest fires (ha or no.)
• Forest extent (Mha, % forest cover)
• Timber quality (How measured?)
• Area affected (e.g. premature felling) by serious pests & diseases
b) Sector economic viability
• Standing sale unit prices
• Private sector annual account reporting: profit or loss
• Employment in forestry and primary wood processing
• Gross Value Added in forestry and primary wood processing
c) Public opinion
• Public opinion survey results (FC statistics)
• Number of forest visitors (public forests only?)/ percent satisfaction
d) Habitat security
• Number of SSSIs in satisfactory condition
• Woodland bird population (National Sustainability Index)
e) Carbon sequestration
• Forest soil carbon „stocks" (per unit forest (type) area)
• Add national scaled-up figures?
f) Water quality and/or quantity
• Chemical quality of water draining forest catchments
• Volume per unit forest area
• Minimum flows from wooded catchments

Table A1.3. Tier 1 impact scores

Name of 'rationalised' consequences (incl. individual impact reference numbers from sectors summary report)	Magnitude <i>Note 1</i>			<i>Note 7</i>	<i>Note 2</i>	<i>Note 3</i>	<i>Note 4</i>	Ranking	<i>For info.</i>	Tier 2 impact?	Comments on selection <i>Note 6</i>
	Economic Score	Environ. Score	Social Score	Vuln. Groups Y/N	Likelihood Score	Urgency Score	Total Score		Average Pedigree		
Pests and diseases (17, 24, 27)	3	3	2	Y	3	3	89	1	3	Yes	Score >30
Drought damage / loss of productivity (3, 7, 8, 12, 14)	3	3	2	Y	2	3	59	2	3	Yes	Score >30
Change in tree species suitability (13, 15, 25)	1	3	1	Y	3	3	56	3	3	Yes	Score >30
Biodiversity loss (16)	1	3	1	N	3	3	56	3	3	Yes	Score >30
Waterlogging (10, 11)	2	2	1	N	2	3	37	5	2	Possible	Score >30. Link to windthrow
Change in soil organic carbon	1	3	1	N	2	3	37	5	1	Possible	Score >30. Covered in Biodiversity sector
Snow and frost damage (6, 22, 23)	1	1	1	N	3	3	33	7	2	Possible	Score >30.
Wind throw (28, 29)	3	3	2	Y	1	3	30	8	2	Possible	Score 30
Fires (5)	2	2	2	Y	2	2	30	9	3	Possible	Score 30. Covered in Biodiversity sector but may require additional work.
Erosion and landslips (9)	1	1	1	N	2	3	22	10	2		
CO2 fertilisation (1, 2)	1	1	1	N	3	1	11	11	3		
Saline incursion (18)	1	1	1	N	3	1	11	11	2		
Emission of volatile compounds (21)	1	2	1	Y	2	1	10	13	2		
Winter hardening (20, 26)	1	2	1	N	2	1	10	13	2		
Oxidation of peatlands (4)	1	1	1	N	2	1	7	15	2		
Weed species (19)	1	1	1	N	2	1	7	15	2		
Invasive flora and fauna	1	1	1	N	2	1	7	15	2		
Increased tourism	1	1	2	N	1	1	5	18	1		
Growing season for nursery stock (30)	1	1	1	N	1	1	4	19	1		

Appendix 2 Social Vulnerability Checklist

The social vulnerability checklist has been carried out on the four broad themes identified in Chapter 3 of this report⁴¹. Each theme takes into account the clustered impacts as identified in Figure 3.1. There is some overlap between impacts and themes; the checklist therefore repeats social vulnerability issues that fit into more than one theme.

These tables have been developed, based on collaborative review by the Forestry Sector Champion and HR Wallingford, updated and broadened in scope by Dr E. O'Brien (Social and Economic Research Group, Forest Research). Sources of evidence have been provided where possible, at the end of this Appendix.

⁴¹ A wide range of 30 impacts and consequences were identified for the forestry sector in Tier 1 and these were arranged, as shown in Figure 3.1, into four main overlapping clusters or themes:

- Woodland habitats: change in climate may influence the habitats and biodiversity of forest ecosystems.
- Timber supply: climate change and extreme weather events can cause damage to timber stocks and also provide opportunities for the forestry sector.
- Industry practices: changes to the growing season and climate related pressures influence the activities of foresters.
- Recreation and local community: potential climate change impacts such as forest fires, erosion, water logging and tree species change can influence the quality and availability of the forest resource for amenity use by people.

Sector	Forestry			
Cluster/ Theme	Woodland Habitats			
Category of social vulnerability factor	Questions to ask	Comment (general answer)	Evidence (opinion, reports, research)	Extent (specifics including data where available)
Place	<p>Which locations are affected by these impacts?</p> <p>Is it spread evenly across regions or not?</p>	<p>Woodland areas, communities who use woodland areas for recreation and business connected with woodlands directly or through tourism, social enterprises, community owned and managed woodlands. Schools, hospitals, social housing estates and prisons with access to woodlands.</p> <p>To understand the distribution of woodlands in the UK, it would be necessary to refer to the FC statistics IFOS data.</p> <p>Trees and woodlands are part of place making and place shaping e.g. improving places where people live and work. Place includes the physical setting as well as people's perceptions and interpretations of that space. A range of research outlines the important contribution that trees and woods can make to people's/communities' sense of place and how they identify with specific places (O'Brien, 2005a, 2006).</p> <p>Trees and woods are considered an important part of England, Scotland and Wales's cultural identity and cultural heritage (Edwards <i>et al.</i>, 2009; Tabbush, 2010).</p> <p>No, density of woodland areas varies with region; refer to IFOS data for details.</p>	<p>The Read Report. Expert opinion (research team), pedigree score 1.</p> <p>O'Brien (2005a), O'Brien (2006), Edwards <i>et al.</i>, (2009), Tabbush (2010).</p> <p>Public opinion of forestry surveys http://www.forestry.gov.uk/forestry/inf-d-5zyl9w (Some of the surveys asked questions about trees and woods as part of the landscape, they also cover questions about use of woods in towns and woods in countryside.)</p> <p>UK Public opinion of Forestry survey (Jamieson and Diggins, 2009) asked about which public benefits are good reasons to support forestry with public money and found 62% stated a reason to support woodlands with public money was to improve the countryside landscape and 44% agreed it was to improve the appearance of towns and cities.</p>	All areas across the UK.
Social	How will people	Potential loss in mature woodland habitat and	Expert opinion (research team), pedigree score 1.	All areas across

Sector	Forestry			
Cluster/ Theme	Woodland Habitats			
Category of social vulnerability factor	Questions to ask	Comment (general answer)	Evidence (opinion, reports, research)	Extent (specifics including data where available)
deprivation	with poor health (physical or mental) be affected by these impacts?	<p>reduction of biodiversity would result in reduction of woodland area/quality. This may reduce the availability of woodland to support the physical and mental wellbeing of some people. Negative impacts on the forestry sector could result in poor mental health (stress, depression) of people whose jobs are in this sector.</p> <p>With the reduction of woodlands as a result of climate change there is likely to be reduced opportunities to use nature in supporting healthy lifestyles.</p> <p>This may also have an impact by reducing volunteering opportunities in woodlands. An in-depth study of 88 volunteers in northern England and southern Scotland found that a quarter were either unemployed, had emotional and behavioural problems or mental health problems (O'Brien <i>et al.</i>, 2011).</p>	<p>There is good evidence of the health benefits of being in woods/forests in terms of increasing physical activity, reducing obesity, physiological benefits (lowering heart rate, reducing muscle tension etc.) and reducing stress and improving cognitive functioning and providing opportunities for social contact (Grahn and Stigsdotter, 2003, O'Brien, 2005b, Townsend, 2006, O'Brien <i>et al.</i>, 2010b, O'Brien <i>et al.</i>, 2011, Lee <i>et al.</i>, 2011).</p> <p>Majority of studies are cross sectional rather than longitudinal.</p> <p>Also Mitchell and Popham (2008) report a strong correlation between the quality of green spaces and improved health outcomes in areas of social deprivation.</p> <p>Contact with woodlands and nature can also improve mood (Pretty <i>et al.</i>, 2005).</p>	<p>the UK.</p> <p>Particular and specific impacts likely in areas identified in the Index of multiple deprivation. Rural deprivation can be masked by more affluent rural dwellers.</p>
	How will people with fewer financial resources be affected?	<p>Reduction in the quantity of woodlands would result in increase of average distance to travel to access woodland. For people in economic hardship, this may mean that they can no longer afford to visit woodland areas.</p> <p>In Scotland, people with lower incomes are less like to live near to or have access to woodlands. This problem would be exacerbated if there were to be a decline in woodland as a result of climate</p>	<p>Expert opinion (research team), pedigree score 1.</p> <p>(Fairburn <i>et al.</i>, (2005).</p> <p>In a meta analysis by Morris <i>et al.</i>, (2011) (sample over 22,000) of existing survey and qualitative research found that significant barriers for those who do not visit woods were:</p> <p>No car – for women, 65yrs+, C2DE (i.e. lower</p>	<p>All areas across the UK.</p> <p>Particular and specific impacts likely in areas identified in the Index of multiple deprivation</p>

Sector	Forestry			
Cluster/ Theme	Woodland Habitats			
Category of social vulnerability factor	Questions to ask	Comment (general answer)	Evidence (opinion, reports, research)	Extent (specifics including data where available)
		<p>change.</p> <p>A key barrier currently to the use of woodlands is the ability to reach woods and forests (Morris <i>et al.</i>, 2011).</p> <p>If there are fewer woods available then this situation is likely to be exacerbated.</p>	<p>socio-economic status), disabled people and white people.</p> <p>For existing visitors barriers of significance included:</p> <p>Woods too far away – ABC1, BME, women, 55yrs+.</p> <p>No car + too far away + mobility reasons – increasing probability either side of 35-45 age range, disabled ($p < 0.01$), female, C2DE ($p < 0.05$).</p>	
	How will people living or working in poor quality homes or workplaces be affected?	<p>Potential for reduced amenity and possible reduction in quality of life.</p> <p>Potential for poor quality homes and workplaces to be located in more deprived areas with lower quality and quantity of woodland habitats and street trees.</p>	<p>Expert opinion (research team), pedigree score 1. Coley <i>et al.</i>, (1997), Kuo (2001), Kuo and Sullivan (2001a), Kuo and Sullivan (2001b), Sullivan <i>et al.</i>, (2004).</p> <p>Research in the United States has explored how trees and shrubs immediately around people's houses (particularly in urban public housing in deprived areas) can have an impact on those who live there in a variety of ways. Tree and shrub cover around buildings as opposed to concrete can increase the resilience of children to deal with life stresses (Wells and Evans, 2003), improve contact with neighbours and social activity (Sullivan <i>et al.</i>, 2004), enable adults to better deal with major life stresses (Kuo, 2001a). Also the greener buildings surroundings are, the fewer crimes (property and</p>	<p>All areas across the UK.</p> <p>Particular and specific impacts likely in areas identified in the Index of multiple deprivation</p>

Sector	Forestry			
Cluster/ Theme	Woodland Habitats			
Category of social vulnerability factor	Questions to ask	Comment (general answer)	Evidence (opinion, reports, research)	Extent (specifics including data where available)
			violent). This may occur because of increased informal surveillance and stress reduction (Kuo and Sullivan, 2001a). Based on correlation rather than causal data.	
	How will people who have limited access to public and private transport be affected?	<p>Lack of mobility to travel to woodland areas influences access to this resource as an amenity. Also note comments associated with people with fewer financial resources.</p> <p>A key barrier currently to use of woodlands is the ability to reach the woods and forests. In a meta analysis (sample over 22,000) of existing survey and qualitative research found that significant barriers for those who do not visit woods were:</p> <p>No car – for women, 65yrs+, C2DE (i.e. lower socio-economic status), disabled people and white people (Morris <i>et al.</i>, 2011).</p> <p>Access is a big issue people prefer local woodlands within 100-400 m of where they live (Coles and Bussey, 2000).</p> <p>Those who want to get involved in volunteering who have with limited access to transport will have reduced opportunities to restore, create, maintain woodland habitats (O'Brien <i>et al.</i>, 2010a).</p>	<p>Expert opinion (research team), pedigree score 1.</p> <p>Coles and Bussey (2000), Morris <i>et al.</i>, (2011), O'Brien <i>et al.</i>, (2010a).</p>	<p>All areas across the UK</p> <p>Particular and specific impacts likely in areas identified in the Index of multiple deprivation.</p> <p>Areas with older populations (over 65), women and those of lower socio-economic status would be affected and potentially children of some of the above.</p>
Disempowerment	How will people with lack of	Potential for such people to not realise what they are missing (in terms of biodiversity, forest	Expert opinion (research team), pedigree score 1.	All areas across the UK.

Sector	Forestry			
Cluster/ Theme	Woodland Habitats			
Category of social vulnerability factor	Questions to ask	Comment (general answer)	Evidence (opinion, reports, research)	Extent (specifics including data where available)
	awareness of the risks be affected?	<p>structure, etc); increased vulnerability of people to falling trees if unaware of wind throw risks.</p> <p>Lack of opportunity for those who do not currently engage with woodland habitats (because of a range of barriers) to be encouraged to become engaged. Potential reduction in resource leading to fewer programmes that try to engage those currently not involved such as Forest School, Forest Education Initiative, organised health walks, cycle rides, therapeutic activities in woodlands.</p> <p>There is a health and safety issue surrounding trees in urban areas – increased risk of branches falling in extreme events can lead to damage of cars and buildings as well as potential to cause injury to people. Assume that this impact is being assessed in the built environment sector.</p>		
	How will people without social networks be affected?	<p>Potentially more vulnerable to reduction of amenity.</p> <p>Trees and woods near to where people live provide opportunities for contact with nearby neighbours as people are more likely to spend time outside (Coley <i>et al.</i>, 1997). This is potentially important for those with few social networks.</p>	<p>Expert opinion (research team), pedigree score 1.</p> <p>Coley <i>et al.</i>, (1997).</p>	All areas across the UK.
	How will people with little	Potentially more vulnerable to reduction of amenity.	Expert opinion (research team), pedigree score 1.	All areas across the UK.

Sector	Forestry			
Cluster/ Theme	Woodland Habitats			
Category of social vulnerability factor	Questions to ask	Comment (general answer)	Evidence (opinion, reports, research)	Extent (specifics including data where available)
	access to systems and support services (e.g. health care) be affected?	<p>Green exercise on prescription for physical and mental health has become more popular in recent years through programmes such as Walking for Health in England and Paths for All in Scotland. These can make important contributions to social capital as well as physical and mental well-being and are an important alternative to gym based GP referrals. Fewer woodlands and trees as part of green infrastructure may reduce the schemes run in woodlands. The Chopwell Wood Health project was a good example of a referral scheme in a woodland (O'Brien and Snowdon, 2007).</p> <p>Reduction in woodland habitats may reduce the opportunities for Forest School and other outdoor education activities which provide benefits especially to children with special needs or emotional and behavioural difficulties (O'Brien, 2005c, O'Brien and Murray, 2007; Roe, 2009).</p>	O'Brien and Snowdon (2007), O'Brien, (2005c). O'Brien and Murray (2007), Roe (2009).	Effect in areas with existing programmes such as education or referrals and potential affect in other areas that might want to start such programmes.
Other	Are any other social vulnerability issues relevant?	<p>Potential change in the availability of non-timber forest products, which would influence those that depend upon them – e.g. cottage industries supplying mushrooms (Emery <i>et al.</i>, 2006).</p> <p>The impact of any decline in forest quality, distribution or quantity, is likely to have a greater impact on middle classes who are currently the people that use forests most as an amenity.</p>	Emery <i>et al.</i> , (2006). Edwards <i>et al.</i> , (2009), Ambrose-Oji (2009), Morris <i>et al.</i> , (2011), Carter <i>et al.</i> , (2011).	<p>All areas across the UK.</p> <p>Potential impact on current woodland users who tend to be those in higher</p>

Sector	Forestry			
Cluster/ Theme	Woodland Habitats			
Category of social vulnerability factor	Questions to ask	Comment (general answer)	Evidence (opinion, reports, research)	Extent (specifics including data where available)
		<p>Vulnerable groups in society do not currently represent as large a proportion of forest users. These groups would, however, have even more reduced opportunities of being involved as active woodland users (Ambrose-Oji, 2009; Edwards <i>et al.</i>, 2009; Morris <i>et al.</i>, 2011).</p> <p>Potential for wind throw to have an impact on subsidence and building structure – but more likely in affluent areas where there are tree-lined streets.</p> <p>Potential reduction in landscape partnership schemes such as Neroche LPS (Carter <i>et al.</i>, 2011) and Grow with Wyre that are diverse partnerships that engage users and non users of woodlands as well as involved communities in decision making about their local landscapes.</p>	Biddle (1998); Roberts <i>et al.</i> , (2006).	<p>socio-economic groups (ABC1), those who are working, 16-54 years olds and those without a disability (Jamieson and Diggins, 2009).</p> <p>Reduced opportunities for those in lower socio-economic groups and deprived areas.</p>

Sector	Forestry			
Cluster/Theme	Timber Supply			
Category of social vulnerability factor	Questions to ask	Comment (general answer)	Evidence (opinion, reports, research)	Extent (specifics including data where available)
Place	<p>Which locations are affected by these impacts?</p> <p>Is it spread evenly across regions or not?</p>	<p>Woodland areas, communities who are dependent on forestry industry, rural and urban areas that require timber for construction. Crafts people and artists that use wood as part of their livelihoods. Timber pulp mills and processing plants are very region specific.</p> <p>No, see note in previous theme.</p>	<p>Expert opinion (research team), pedigree score 1.</p> <p>The Read Report.</p> <p>Edwards <i>et al.</i>, (2009).</p>	<p>All areas across the UK.</p> <p>Area more reliant on forestry sector and its products.</p>
Social deprivation	How will people with poor health (physical or mental) be affected by these impacts?	Potential reduction of timber supply would increase cost of building materials and have cascading impacts on the cost of providing amenities (such as benches, health surgeries, community centres etc) and/or services (such as supporting health services or community groups) to people with poor health.	Expert opinion (research team), pedigree score 1.	<p>All areas across the UK.</p> <p>Area more reliant on forestry sector and its products.</p>
	How will people with fewer financial resources be affected?	<p>Reduction in timber supply would increase cost of construction and increase hardship on the economically deprived.</p> <p>Increased costs of woodfuel could mean those with less income could not potentially afford to move to</p>	Expert opinion (research team), pedigree score 1.	All areas across the UK.

Sector	Forestry			
Cluster/Theme	Timber Supply			
Category of social vulnerability factor	Questions to ask	Comment (general answer)	Evidence (opinion, reports, research)	Extent (specifics including data where available)
		more sustainable lifestyles which is advocated by government.		
	How will people living or working in poor quality homes or workplaces be affected?	Number of people in this situation could increase because of increasing cost of construction.	Expert opinion (research team), pedigree score 1.	All areas across the UK.
	How will people who have limited access to public and private transport be affected?	Potentially fewer jobs in timber industry would lead to more (further) travel to existing forest sector work.	Expert opinion (research team), pedigree score 1.	All areas across the UK.
Disempowerment	How will people with lack of awareness of the risks be affected?	No known impact.	Expert opinion (research team), pedigree score 1.	All areas across the UK.
	How will people without social networks be affected?	If those work in the sector lose their job this can increase social isolation, as a major form of social contact with others is through work. If this occurs in rural areas then it may be difficult to find alternative employment.	Expert opinion (research team), pedigree score 1. Layard (2005) outlines the impact of unemployment on well-being.	All areas across the UK.
	How will people with little access to systems and support services (e.g. health care) be affected?	Number of people in this situation could increase because of increasing cost of construction – although this is very unlikely. Potential for job losses in the timber industry for workers and if they cannot find other work there is	Expert opinion (research team), pedigree score 1. Layard (2005). Outlines that people do not habituate to unemployment even after 1-2	All areas across the UK.

Sector	Forestry			
Cluster/Theme	Timber Supply			
Category of social vulnerability factor	Questions to ask	Comment (general answer)	Evidence (opinion, reports, research)	Extent (specifics including data where available)
		potential for this to lead to health issues (particularly mental health problems) (Layard, 2005).	years.	
Other	Are any other social vulnerability issues relevant?	<p>Impacts on timber supply would have associated consequences for related industries and could therefore result in economic difficulties as well as opportunities for people working in forestry, constructions and related sectors.</p> <p>There would be an impact on building aesthetics if the use of timber in construction declines and this would have consequences for quality of environment for the most vulnerable sections of society.</p>	Expert opinion (research team), pedigree score 1.	All areas across the UK.

Sector	Forestry			
Cluster/Theme	Industry Practices			
Category of social vulnerability factor	Questions to ask	Comment (general answer)	Evidence (opinion, reports, research)	Extent (specifics including data where available)
Place	<p>Which locations are affected by these impacts?</p> <p>Is it spread evenly across regions or not?</p>	<p>Woodland areas, communities who are dependent on forestry industry, communities that own or manage woodland, woodland social enterprises, communities with access to woodland for recreation.</p> <p>No, see note in previous theme.</p>	<p>Expert opinion (research team), pedigree score 1.</p> <p>Edwards <i>et al.</i>, (2009) found in 2007/8 in Scotland the total employment (i.e. direct, indirect and induced) in the Scottish forestry sector associated with the use of Scottish timber is estimated to be 13 200 Full-Time Equivalent (FTE) jobs. This breaks down into 10 300 FTEs for direct employment, 1500 FTEs for indirect employment, and 1400 FTEs for induced employment. The figure for direct employment equates to around 12 000 jobs, since not all employment is full-time. These estimates are based upon a broad definition of the forestry sector that includes: forestry harvesting and planting; farm woodlands; haulage; primary wood processing; pulp and paper; and public sector, non-governmental organisation, and research and education employment that is associated with Scottish forests. However the estimates exclude employment</p>	<p>All areas across the UK.</p> <p>Particular impact on areas dependent on forestry sector.</p>

Sector	Forestry			
Cluster/Theme	Industry Practices			
Category of social vulnerability factor	Questions to ask	Comment (general answer)	Evidence (opinion, reports, research)	Extent (specifics including data where available)
			associated with the use of timber not grown in Scotland. In addition, the total employment because of first-round (direct) spending from tourism and recreation attributable to woodland, where woodland was the primary reason for the visit, is estimated to be around 17 900 FTE jobs.	
Social deprivation	How will people with poor health (physical or mental) be affected by these impacts?	Damage to trees, reduction of woodland quality and/or quantity and consequences associated with the management of pests and pathogens could result in loss of amenity.	Expert opinion (research team), pedigree score 1. Ambrose-Oji (2009). See previous details on health benefits of trees and woods.	All areas across the UK.
	How will people with fewer financial resources be affected?	Reduction in the quantity of woodlands would result in increase of average distance to travel to access woodland. For people in economic hardship, this may mean that they can no longer afford to visit woodland areas.	Expert opinion (research team), pedigree score 1. Fairburn <i>et al.</i> , (2005), Edwards <i>et al.</i> , (2009), Morris <i>et al.</i> , (2011). The total GVA (direct, indirect and induced) associated with Scottish timber is estimated to be around £460 million at 2007/08 prices, or 0.5% of the total GVA for the Scottish economy. This total breaks down into £304 million for direct GVA, £86 million for indirect GVA and £69 million for induced	All areas across the UK.

Sector	Forestry			
Cluster/Theme	Industry Practices			
Category of social vulnerability factor	Questions to ask	Comment (general answer)	Evidence (opinion, reports, research)	Extent (specifics including data where available)
			<p>GVA. These estimates are based on the broad definition of the forestry sector outlined above, excluding GVA associated with the use of timber not grown in Scotland.</p> <p>In addition, the GVA of first-round (direct) visitor spending attributable to woodland visits, where woodland was the primary reason for the visit, is estimated to be £209 million at 2007/08 prices (Edwards <i>et al.</i>, 2009).</p>	
	How will people living or working in poor quality homes or workplaces be affected?	Potential for reduced amenity.	Expert opinion (research team), pedigree score 1.	All areas across the UK.
	How will people who have limited access to public and private transport be affected?	Lack of mobility to travel to woodland areas influences access to this resource as an amenity (Morris <i>et al.</i> , 2011).	Expert opinion (research team), pedigree score 1. Morris <i>et al.</i> , (2011).	All areas across the UK.
Disempowerment	How will people with lack of awareness of the risks be affected?	Potential for such people to not realise what they are missing (in terms of biodiversity, forest structure etc).	Expert opinion (research team), pedigree score 1.	All areas across the UK.
	How will people without social networks be affected?	Potentially more vulnerable to reduction of amenity and lack of opportunity to use woodlands or participate in woodland	Expert opinion (research team), pedigree score 1. Fairburn <i>et al.</i> , (2005), O'Brien and	All areas across the UK.

Sector	Forestry			
Cluster/Theme	Industry Practices			
Category of social vulnerability factor	Questions to ask	Comment (general answer)	Evidence (opinion, reports, research)	Extent (specifics including data where available)
		programmes that encourage social interaction (O'Brien and Morris, 2009).	Morris (2009).	
	How will people with little access to systems and support services (e.g. health care) be affected?	Potentially more vulnerable to reduction of amenity.	Expert opinion (research team), pedigree score 1. Fairburn <i>et al.</i> , (2005).	All areas across the UK. Particularly those in deprived areas and the socially isolated which includes older populations.
Other	Are any other social vulnerability issues relevant?	Potential reduction in woodland apprenticeship schemes where people can learn and develop industry skills. Potential reduction in woodland social enterprises (O'Brien, 2005c).	Expert opinion (research team), pedigree score 1. O'Brien (2005c).	All areas across the UK.

Sector	Forestry			
Cluster/Theme	Recreation and local community			
Category of social vulnerability factor	Questions to ask	Comment (general answer)	Evidence (opinion, reports, research)	Extent (specifics including data where available)
Place	<p>Which locations are affected by these impacts?</p> <p>Is it spread evenly across regions or not?</p>	<p>Woodland areas, communities with access to woodland for recreation, community owned and managed woodlands. Business that rely in partly on woodlands e.g. tourism related. Schools, hospitals, social housing areas and prisons with access to woodlands. People and communities sense of place could be affected in a variety of ways from changes in quality and quantity (O'Brien, 2005a).</p> <p>Trees and woodlands are part of place making and place shaping e.g. improving places where people live and work. Place includes the physical setting as well as people's perceptions and interpretations of that space. A range of research reports on the important contribution that trees and woods can make to people's/communities' sense of place and how they identify with specific places (O'Brien, 2005a, 2006).</p> <p>Trees and woods are considered an important part of England,</p>	<p>Expert opinion (research team), pedigree score 1.</p> <p>Governance of community forests and woodlands in Britain – various reports available at: http://www.forestry.gov.uk/fr/INFD-7TSD7E</p> <p>O'Brien, (2005a, 2006), Edwards <i>et al.</i>, (2009), Tabbush (2010).</p>	All areas across the UK.

Sector	Forestry			
Cluster/Theme	Recreation and local community			
Category of social vulnerability factor	Questions to ask	Comment (general answer)	Evidence (opinion, reports, research)	Extent (specifics including data where available)
		Scotland and Wales's cultural identity and cultural heritage (Edwards <i>et al.</i> , 2009; Tabbush, 2010). No, see note in previous theme.		
Social deprivation	How will people with poor health (physical or mental) be affected by these impacts?	Damage to trees, reduction of woodland quality and/or quantity and hazards such as fires, erosion and water-logging could result in loss of amenity. People with mental health problems could suffer anxiety caused by fires, erosion and wind throw. Increased emission of volatile compounds could have detrimental impacts on people with health issues. Potentially poorer air quality because of fewer trees may also impact on health (Lovasi <i>et al.</i> , 2008). Potential reduction in noise pollution potential with fewer trees. Increase in urban heat island with fewer trees (Harlan <i>et al.</i> , 2006). Reduction in quality and quantity may affect a wide range of people.	The Read Report. Maas <i>et al.</i> , (2009). Nordh <i>et al.</i> , (2009). Kuo and Taylor (2004). Lovasi <i>et al.</i> , (2008), Kuo (2001), Ulrich (1984), Grahn and Stigsdotter (2003). Hansmann <i>et al.</i> , (2007). Harlan <i>et al.</i> , (2006) Kaplan (1992) Mitchell and Popham (2008), Social and Economic Research Group, 2008), MIND (2007), Nilsson <i>et al.</i> , (2011).	All areas across the UK. Those high on the Index of multiple deprivation and areas where people have poorer health are likely to be most effected. Public health observatories will hold specific data on population health. Urban areas that are hotter and suffer from greater pollution more likely to suffer from tree reduction.

Sector	Forestry			
Cluster/Theme	Recreation and local community			
Category of social vulnerability factor	Questions to ask	Comment (general answer)	Evidence (opinion, reports, research)	Extent (specifics including data where available)
		<p>Research has shown that those who look out of hospitals wards on to trees rather than other buildings take less medication and were discharged from hospital sooner (Ulrich, 1984).</p> <p>The importance of ecotherapy is advocated by MIND for mild and moderate depression (MIND, 2007).</p> <p>Woodlands have been shown to be restorative for a wide range of people within society (Kaplan, 1992).</p> <p>The non-market value of visits to Scottish woodlands by Scottish adults is estimated to be between £44 million and £76 million per year (Edwards <i>et al.</i>, 2009). A key reason to visit it to undertake some form of activity.</p> <p>The Cyd Coed funded programme in Wales provided grant to 163 community groups from 2001-2008 in Objective 1 areas (those areas that are more deprived). An evaluation of the programme found that approximately 18,000 school</p>		

Sector	Forestry			
Cluster/Theme	Recreation and local community			
Category of social vulnerability factor	Questions to ask	Comment (general answer)	Evidence (opinion, reports, research)	Extent (specifics including data where available)
		<p>children have been involved to some degree in Cydcoed projects. Project groups have 8,955 members and work with a further 6,490 people from other community groups. Over half of those questioned agreed their level of trust in the community had increased as a result of taking part in a Cydcoed project and around 75% agreed that they knew more people as a result of Cydcoed. Over 90% in a survey felt the woods played an important part in creating a sense of well-being (Social and Economic Research Group, 2008).</p> <p>The NHS Forest is being developed in England and Scotland with projects focused on increasing tree cover and improving existing greenspace around hospitals (NHS Forest, 2011).</p>		
	How will people with fewer financial resources be affected?	Reduction in the quantity of woodlands would result in increase of average distance to travel to access woodland. For people in economic hardship, this may mean	Expert opinion (research team), pedigree score 1. Marmot (2010), O'Brien (2006), Pinder <i>et al.</i> , (2009), Pretty <i>et al.</i> , (2005), Morris <i>et al.</i> , (2011), Stewart	All areas across the UK. Particularly areas with populations of those in lower socio-economic groups, those with

Sector	Forestry			
Cluster/Theme	Recreation and local community			
Category of social vulnerability factor	Questions to ask	Comment (general answer)	Evidence (opinion, reports, research)	Extent (specifics including data where available)
		<p>that they can no longer afford to visit woodland areas.</p> <p>Reduction in quantity of woodlands may have impacts on programmes that focusing on creating woods near to where people live in urban areas. For example the Woodlands in and Around Towns programmes in Scotland, the regeneration of brownfield sites in areas such as the North-west of England.</p> <p>The Marmot (2010) review on health inequalities recommended improvements to access and quality of open and green spaces across the social gradient.</p> <p>A key barrier currently to the use of woodlands is the ability to reach woods and forests (Morris <i>et al.</i>, 2011). Those that are currently underrepresented in woodland use may continue to experience barriers to access including black and minority ethnic groups, older people, those of lower socio-economic status and those with disabilities (Stewart and O'Brien, 2010).</p>	and O'Brien (2010b).	disabilities, older people and black and minority ethnic groups.

Sector	Forestry			
Cluster/Theme	Recreation and local community			
Category of social vulnerability factor	Questions to ask	Comment (general answer)	Evidence (opinion, reports, research)	Extent (specifics including data where available)
		If there are fewer woods available then this situation is likely to be exacerbated.		
	How will people living or working in poor quality homes or workplaces be affected?	<p>Potential for reduced amenity, reduced social activity, and reduction in resilience to stressful events with poorer quality surroundings combined with poor quality homes.</p> <p>Potential impact on children accessing woods. Louv (2005) outlines the concept of nature deficit disorder and talks about the extinction of experience. Ward Thompson outlines that use of woods as a child is key indicator of adult use of woods (Ward Thompson <i>et al.</i>, 2008).</p>	<p>Expert opinion (research team), pedigree score 1.</p> <p>Coley <i>et al.</i>, (1997), Kuo (2001), Kuo and Sullivan (2001a), Kuo and Sullivan (2001b), Sullivan <i>et al.</i>, (2004), Louv (2005), Ward Thompson <i>et al.</i>, (2008).</p> <p>Research in the United States has explored how trees and shrubs immediately around people's houses (particularly in urban public housing in deprived areas) can have an impact on those who live there in a variety of ways. Tree and shrub cover around buildings as opposed to concrete can increase the resilience of children to deal with life stresses (Wells and Evans, 2003), improve contact with neighbours and social activity (Sullivan <i>et al.</i>, 2004), enable adults to better deal with major life stresses (Kuo, 2001). Also the greener buildings surroundings</p>	<p>All areas across the UK.</p> <p>Potentially areas with social housing in deprived areas may be most affected and the children living in these places.</p>

Sector	Forestry			
Cluster/Theme	Recreation and local community			
Category of social vulnerability factor	Questions to ask	Comment (general answer)	Evidence (opinion, reports, research)	Extent (specifics including data where available)
			the fewer crimes (property and violent) this potentially occurs because of increased informal surveillance and stress reduction (Kuo and Sullivan, 2001a).	
	How will people who have limited access to public and private transport be affected?	<p>Lack of mobility to travel to woodland areas influences access to this resource as an amenity or to volunteer in woodland habitats. In natural hazard situation (fire, flooding, erosion), people in rural woodland locations would be less able to evacuate in emergency.</p> <p>A key barrier currently to the use of woodlands is the ability to reach woods and forests (Morris <i>et al.</i>, 2011).</p> <p>If there are fewer woods available then this situation is likely to be exacerbated.</p> <p>An important issue for deprived populations is the restrictions that can occur in people's horizons and movements which can be specifically limited. The Active England evaluation found that a father's group living on a deprived estate in Swindon kept very much</p>	<p>Expert opinion (research team), pedigree score 1.</p> <p>Morris <i>et al.</i>, (2011), O'Brien and Morris (2009).</p>	<p>All areas across the UK.</p> <p>Greatest impact on those in deprived areas of lower socio-economic status and potentially older people.</p>

Sector	Forestry			
Cluster/Theme	Recreation and local community			
Category of social vulnerability factor	Questions to ask	Comment (general answer)	Evidence (opinion, reports, research)	Extent (specifics including data where available)
		to the estate and had not visited a country park on the edge of Swindon (O'Brien and Morris, 2009).		
Disempowerment	How will people with lack of awareness of the risks be affected?	<p>Potential for such people to not realise what they are missing (in terms of biodiversity, forest structure etc). More vulnerable to natural hazards.</p> <p>Less resource may lead to fewer activities and programmes associated with woodlands such as volunteering, education through Forest School or the Forest Education Initiative, health walks, bushcraft days etc. This could reduce the opportunities to engage those who currently lack awareness of the opportunities.</p>	<p>Expert opinion (research team), pedigree score 1.</p> <p>Fairburn <i>et al.</i>, (2005)</p>	All areas across the UK.
	How will people without social networks be affected?	<p>Potentially more vulnerable to reduction of amenity and natural hazards.</p> <p>Trees and woods near to where people live provide opportunities for contact with nearby neighbours as people are more likely to spend time outside (Coley <i>et al.</i>, 1997). This is potentially important for</p>	<p>Expert opinion (research team), pedigree score 1.</p> <p>Fairburn <i>et al.</i>, (2005), Coley <i>et al.</i>, (1997), Stewart and O'Brien (2010).</p>	All areas across the UK.

Sector	Forestry			
Cluster/Theme	Recreation and local community			
Category of social vulnerability factor	Questions to ask	Comment (general answer)	Evidence (opinion, reports, research)	Extent (specifics including data where available)
		those with few social networks. Woodlands and woodland interventions can help build a strong sense of belonging, improve social inclusion and community cohesion, and enhance community capacity to achieve shared goals through increased social capital (Stewart and O'Brien, 2010).		
	How will people with little access to systems and support services (e.g. health care) be affected?	Potentially more vulnerable to reduction of amenity and natural hazards. Green exercise on prescription for physical and mental health has become more popular in recent years through programmes such as Walking for Health in England and Paths for All in Scotland. These can make important contributions to social capital as well as physical and mental well-being and are an important alternative to gym based GP referrals. Fewer woodlands and trees as part of green infrastructure may reduce the schemes that are run in woodlands. The Chopwell Wood Health project was a good example of a referral scheme in a	Expert opinion (research team), pedigree score 1. Fairburn <i>et al.</i> , (2005), O'Brien and Snowdon (2007), Nilsson <i>et al.</i> , (2011).	All areas across the UK. Those in deprived areas likely to be most affected.

Sector	Forestry			
Cluster/Theme	Recreation and local community			
Category of social vulnerability factor	Questions to ask	Comment (general answer)	Evidence (opinion, reports, research)	Extent (specifics including data where available)
		<p>woodland (O'Brien and Snowdon, 2007).</p> <p>Contribution that woodlands can play in mental, physical and social well-being can be an important resource for those with little access to support services (Nilsson <i>et al.</i>, 2011).</p>		
Other	Are any other social vulnerability issues relevant?	<p>Accessibility could be a major issue and accessibility to welcoming spaces with facilities that enable use (Carter <i>et al.</i>, 2008).</p> <p>Social impacts from pests and pathogens – reduced aesthetic quality, exclusion zones, public health danger.</p>	<p>Expert opinion (research team), pedigree score 1.</p> <p>Carter <i>et al.</i>, (2008).</p>	All areas across the UK.

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Appendix 3 Response Functions

The details provided in this Appendix give further information on the development of the response functions for assessing how each risk metric could respond to changes in climate.

Forest extent affected by pests and pathogens

The review of Tier 1 impacts and consultation with stakeholders and experts identified the importance exploring the relationship of pests and pathogen risk with climate change. Establishing a causal link between climate change and pest/pathogen outbreak is, however, difficult. The Read Report suggested that there is little evidence in the UK that past climate change has influenced pest or pathogen prevalence or severity and that the dominant factor influencing spread and impact has been international trade and import of contaminated materials such as timber and live trees. Nevertheless, despite limited existing evidence linking general trends in climate and pest and pathogen damage to forests, there has been considerable research that has shown that pest/pathogen biology and life cycles are related to climatic conditions, e.g. Woods *et al.* (2005), Brown and Webber (2008), Sturrock *et al.* (2011), and that climate change is likely to exert a future effect which could be significant in many cases (Evans *et al.*, 2002; Lonsdale and Gibbs, 2002). Based on the premise that if climatic conditions influence the success of a pest or pathogen establishing, breeding and spreading, then a change in climatic conditions is likely to change these life cycle stages and therefore influence their prevalence and severity. The response functions developed and explained below assume a causal link between climate and pest/pathogen damage but it is recognised that the basis of these functions is associated with high uncertainty, and further research is required.

Metric FO1 considers the aerial extent of woodland that could be affected by pests and pathogens, taking 'affected' to mean that the prevalence of pests or pathogens is sufficiently severe to cause a reduction of productivity, timber quality and/or a change in forest management practice. In the absence of data or model outputs on climate impacts on pests and pathogens, this risk metric has been assessed using a semi-quantitative, expert judgement approach. It is not appropriate to aggregate the impacts of pests and pathogens as the biology of each pest/pathogen is different and all have different controlling influences. This metric has, therefore, been split into two *example* metrics that describe the relationship of one pest and one pathogen to climate. These are:

- FO1a Forest extent affected by red band needle blight
- FO1b Forest extent affected by green spruce aphid.

The two examples were selected because these pests and diseases are already present within the UK, considerable research has been undertaken on their biology and their behaviour to climate has been brought out in the scientific literature. However, the main limitations with the response functions derived include:

- The response functions are developed on the basis that climate change and pest/pathogen prevalence and severity are linked; scientific authorities have alluded to this in the literature but more evidence is required to support this hypothesis.
- The research cited gives some indication of conditions required for spread of pests/pathogens but quantifying the actual magnitude of impact (i.e.

proportion of extent affected) in these optimal conditions is highly subjective.

- The response functions assume that optimum climate conditions for spread will lead to all forest extent being affected but this may be too conservative.
- The figures for the magnitude of temperature increase required to reach the threshold of maximum spread (i.e. baseline temperatures) have been assessed at a national (i.e. British) scale.
- The focus on temperature, the most significant climatic variable from the literature, excludes consideration of much more complex meteorological 'models', for example such as that discussed by Watt *et al.* (2009). This is likely to induce high uncertainty to the projected forest effects.
- The focus on only one insect and one pathogen exemplifies some aspects of the relationship between pests and pathogens and climate drivers, but there are many others.
- The focus on the relationship between pest/pathogen and climate ignores the relationship between host (i.e. tree) and climate. This complex relationship will be very pest/host-specific and so will the consequent risk.

Forest extent affected by Red Band Needle Blight

Increased rainfall in spring and summer, coupled with a trend towards warmer springs are considered as key drivers determining the prevalence of this fungal pathogen (Brown and Webber, 2008). Relative humidity is also considered important, as there is some evidence that the disease spreads under highly humid conditions. Average spring humidity in London and Wales is, however, between 70% and 80% and the maximum percentage change in humidity levels from the UKCP09 projections would not move the levels outside of this current range. Temperature change is, therefore, likely to be the dominant climate variable influencing the spread of the disease. Relating the spread of the pathogen to the potential increase of spring temperature was considered; the baseline mean spring temperatures are, however, lower than the published conditions for optimum spread and the projected increase in temperatures would not push into this range. Brown and Webber (2008) suggest that germination may occur through spring and early summer, and given that summer temperatures are higher than spring temperatures, an increase in summer temperatures into the optimum ranges for pathogen spread may be significant. The response function therefore related pathogen spread to mean summer temperature.

A baseline condition of the areal extent of the three pine species susceptible to the disease (Scots pine, lodgepole pine and Corsican pine) of approximately 400,000 hectares is assumed (see Forestry Commission statistics⁴²). In addition, a current baseline forest extent of 45,000 hectares of pine affected by the disease is proposed (Anna Brown, pers. comm.).

The optimum condition for establishment is 12-18°C (Brown and Webber, 2008), with maximum growth rates at 16 to 20°C (Gadgil, 1968). The maximum temperature limit for growth is 31°C. The largest extent of Scots pine and lodgepole pine forests are in Scotland, where temperature increase needs to be greater to stay within the maximum growing conditions temperature range. We assume that a temperature change that increases temperature above the maximum growing conditions will have increased gradually and hence spread has already achieved maximum and response function plateaus rather than dips back down.

⁴² <http://www.forestry.gov.uk/website/forstats2010.nsf/LUContentsTop?openview&RestrictToCategory=1>

The qualitative response function for RBNB is given in Table A3.1 and Table A3.2 shows the distribution of pine species in England, Wales and Scotland; the greatest pine forest extent is in Scotland and with a lower baseline average summer temperature than England, a greater increase in temperature would be required to reach optimum conditions for pathogen establishment. The analysis assumes no change for baseline area extent of pine forest (as given in Table A3.2). There is a difference in the sensitivity of different tree species; Corsican pine is more sensitive to exposure than Scots pine.

Table A3.1. Response Function for FO1a: Forest extent affected by red band needle blight. The numbers in the table are percentage likelihood scores based on expert judgement input

Magnitude class	Estimated change in metric (response can span classes)								Metric description	Class value
very high	0	0	10	89	89	89	89	89	All pine forests affected: >400 thousand hectares	5
high	0	0	80	11	11	11	11	11	> 200 thousand	4
medium	0	10	10	0	0	0	0	0	>100 thousand	3
low	0	80	0	0	0	0	0	0	> 50 thousand	2
very low	100	10	0	0	0	0	0	0	Baseline: current area (45K) of pine forest affected.	1
	0	1	2	3	4	5	6	7		
Change in mean summer temperature degrees celsius										

Table A3.2. Pine forest extent ('000 hectares). Source: Forestry Statistics, 2010

	England	Wales	Scotland	GB
Scots pine	82	5	140	227
Corsican pine	41	3	2	46
Lodgepole pine	7	6	122	135
	130	14	264	408

The two tables below show the results from applying the response function for FO1a to the UKCP09 data, but should only be used as an indicative picture of the relative risk in each region because of the assumptions made in the methodology.

Since the response function for RBNB relates increasing mean summer temperature with increasing prevalence of the pathogen, regions with the highest mean summer temperatures are most at risk and regions with the biggest change between baseline temperatures and projected temperatures are likely to see the greatest change in the level of risk.

Table A3.3. Most likely magnitude of impact of Red Band Needle Blight on forests from projected change in mean summer temperature

Region	2020s			2050s			2080s			Emission Scenario
	p10	p50	p90	p10	p50	p90	p10	p50	p90	
Channel Islands				very low	high	very high	low	high	very high	Low Emission
East Midlands				very low	high	very high	low	high	very high	
East of England				low	high	very high	low	high	very high	
Eastern Scotland				low	high	very high	low	high	very high	
Isle of Man				low	high	very high	low	high	very high	
London				low	high	very high	low	high	very high	
North East England				low	high	very high	low	high	very high	
North West England				low	high	very high	low	high	very high	
Northern Ireland				very low	low	very high	low	high	very high	
Northern Scotland				very low	low	very high	low	high	very high	
South East England				low	high	very high	low	high	very high	
South West England				low	high	very high	low	high	very high	
Wales				very low	high	very high	low	high	very high	
West Midlands				low	high	very high	low	high	very high	
Western Scotland				low	high	very high	low	high	very high	
Yorkshire and Humberside				very low	high	very high	low	high	very high	
Channel Islands	very low	low	high	low	high	very high	low	very high	very high	Medium Emission
East Midlands	very low	low	high	low	high	very high	low	very high	very high	
East of England	very low	low	high	low	high	very high	low	very high	very high	
Eastern Scotland	very low	low	high	low	high	very high	low	very high	very high	
Isle of Man	very low	low	high	low	high	very high	low	very high	very high	
London	very low	low	high	low	high	very high	high	very high	very high	
North East England	very low	low	high	low	high	very high	low	very high	very high	
North West England	very low	low	high	low	high	very high	low	very high	very high	
Northern Ireland	very low	low	high	low	high	very high	low	very high	very high	
Northern Scotland	very low	low	high	very low	high	very high	low	high	very high	
South East England	very low	low	high	low	high	very high	high	very high	very high	
South West England	very low	low	high	low	high	very high	high	very high	very high	
Wales	very low	low	high	low	high	very high	low	very high	very high	
West Midlands	very low	low	high	low	high	very high	low	very high	very high	
Western Scotland	very low	low	high	low	high	very high	low	very high	very high	
Yorkshire and Humberside	very low	low	high	low	high	very high	low	very high	very high	
Channel Islands				low	high	very high	high	very high	very high	High Emission
East Midlands				low	high	very high	high	very high	very high	
East of England				low	high	very high	high	very high	very high	
Eastern Scotland				low	high	very high	high	very high	very high	
Isle of Man				low	high	very high	high	very high	very high	
London				low	very high	very high	high	very high	very high	
North East England				low	high	very high	high	very high	very high	
North West England				low	high	very high	high	very high	very high	
Northern Ireland				low	high	very high	high	very high	very high	
Northern Scotland				low	high	very high	low	very high	very high	
South East England				low	very high	very high	high	very high	very high	
South West England				low	very high	very high	high	very high	very high	
Wales				low	high	very high	high	very high	very high	
West Midlands				low	high	very high	high	very high	very high	
Western Scotland				low	high	very high	high	very high	very high	
Yorkshire and Humberside				low	high	very high	high	very high	very high	

Table A3.4. Expected magnitude of impact of Red Band Needle Blight on forests from projected change in mean summer temperature

Region	2020s			2050s			2080s			Emission Scenario
	p10	p50	p90	p10	p50	p90	p10	p50	p90	
Channel Islands				1.97	4.22	4.89	2.46	4.61	4.89	Low Emission
East Midlands				2.00	4.27	4.89	2.39	4.61	4.89	
East of England				2.06	4.32	4.89	2.48	4.65	4.89	
Eastern Scotland				2.10	4.18	4.89	2.47	4.57	4.89	
Isle of Man				2.01	4.10	4.89	2.41	4.44	4.89	
London				2.19	4.49	4.89	2.63	4.87	4.89	
North East England				2.25	4.33	4.89	2.73	4.72	4.89	
North West England				2.29	4.34	4.89	2.76	4.74	4.89	
Northern Ireland				1.86	3.89	4.89	2.21	4.31	4.89	
Northern Scotland				1.88	3.80	4.89	2.11	4.24	4.89	
South East England				2.26	4.51	4.89	2.67	4.87	4.89	
South West England				2.18	4.39	4.89	2.71	4.82	4.89	
Wales				1.97	4.18	4.89	2.46	4.57	4.89	
West Midlands				2.10	4.29	4.89	2.59	4.71	4.89	
Western Scotland				2.12	4.19	4.89	2.54	4.55	4.89	
Yorkshire and Humberside				1.92	4.15	4.89	2.25	4.46	4.89	
Channel Islands	1.46	2.84	4.44	2.34	4.46	4.89	3.81	4.89	4.89	Medium Emission
East Midlands	1.53	2.80	4.42	2.31	4.41	4.89	3.65	4.89	4.89	
East of England	1.54	2.86	4.46	2.35	4.46	4.89	3.74	4.89	4.89	
Eastern Scotland	1.59	2.86	4.38	2.19	4.32	4.89	3.53	4.89	4.89	
Isle of Man	1.54	2.67	4.18	2.19	4.23	4.89	3.49	4.89	4.89	
London	1.57	3.11	4.65	2.53	4.66	4.89	4.02	4.89	4.89	
North East England	1.62	3.00	4.42	2.47	4.49	4.89	3.95	4.89	4.89	
North West England	1.64	3.04	4.43	2.49	4.50	4.89	3.99	4.89	4.89	
Northern Ireland	1.44	2.54	4.17	2.04	4.16	4.89	3.35	4.89	4.89	
Northern Scotland	1.49	2.47	4.08	1.93	4.02	4.89	3.02	4.88	4.89	
South East England	1.59	3.12	4.66	2.59	4.65	4.89	4.04	4.89	4.89	
South West England	1.54	3.08	4.61	2.60	4.66	4.89	4.08	4.89	4.89	
Wales	1.48	2.79	4.39	2.36	4.42	4.89	3.77	4.89	4.89	
West Midlands	1.52	2.94	4.51	2.46	4.55	4.89	3.96	4.89	4.89	
Western Scotland	1.57	2.80	4.29	2.32	4.34	4.89	3.68	4.89	4.89	
Yorkshire and Humberside	1.49	2.63	4.27	2.17	4.28	4.89	3.47	4.89	4.89	
Channel Islands				2.56	4.74	4.89	4.42	4.89	4.89	High Emission
East Midlands				2.65	4.71	4.89	4.30	4.89	4.89	
East of England				2.66	4.77	4.89	4.35	4.89	4.89	
Eastern Scotland				2.62	4.65	4.89	4.20	4.89	4.89	
Isle of Man				2.59	4.56	4.89	4.22	4.89	4.89	
London				2.85	4.89	4.89	4.52	4.89	4.89	
North East England				2.95	4.86	4.89	4.47	4.89	4.89	
North West England				2.95	4.88	4.89	4.48	4.89	4.89	
Northern Ireland				2.27	4.38	4.89	4.10	4.89	4.89	
Northern Scotland				2.26	4.31	4.89	3.77	4.89	4.89	
South East England				2.93	4.89	4.89	4.55	4.89	4.89	
South West England				2.83	4.89	4.89	4.61	4.89	4.89	
Wales				2.56	4.70	4.89	4.38	4.89	4.89	
West Midlands				2.72	4.83	4.89	4.50	4.89	4.89	
Western Scotland				2.75	4.68	4.89	4.32	4.89	4.89	
Yorkshire and Humberside				2.42	4.56	4.89	4.17	4.89	4.89	

Forest extent affected by green spruce aphid

Figure A3.1 shows the relationship between mean winter temperature and percentage of trees showing insect damage between 1989 and 2003. There is no discernable correlation between average winter temperature and pest damage over this time period.

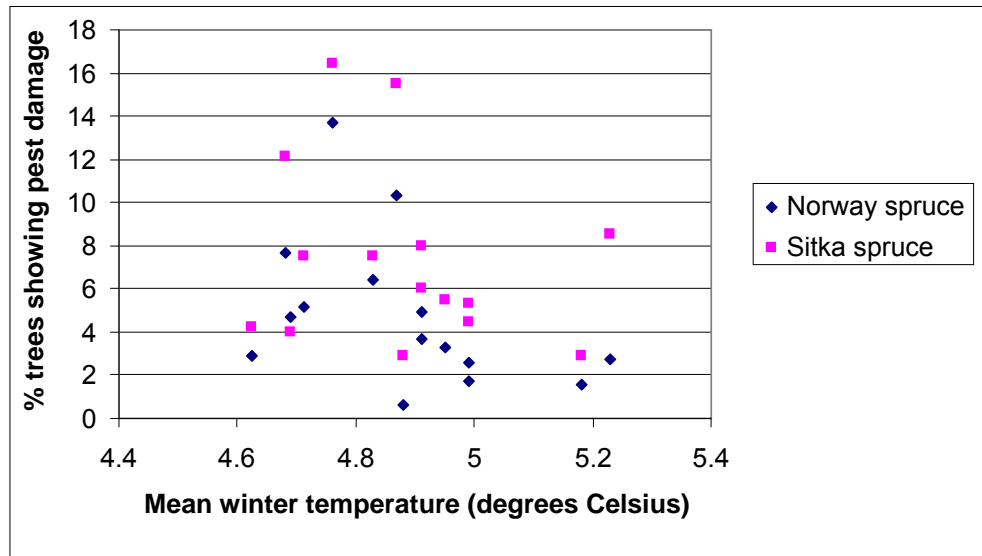


Figure A3.1. Percentage of trees in England, Wales and Scotland showing abundance insect damage⁴³

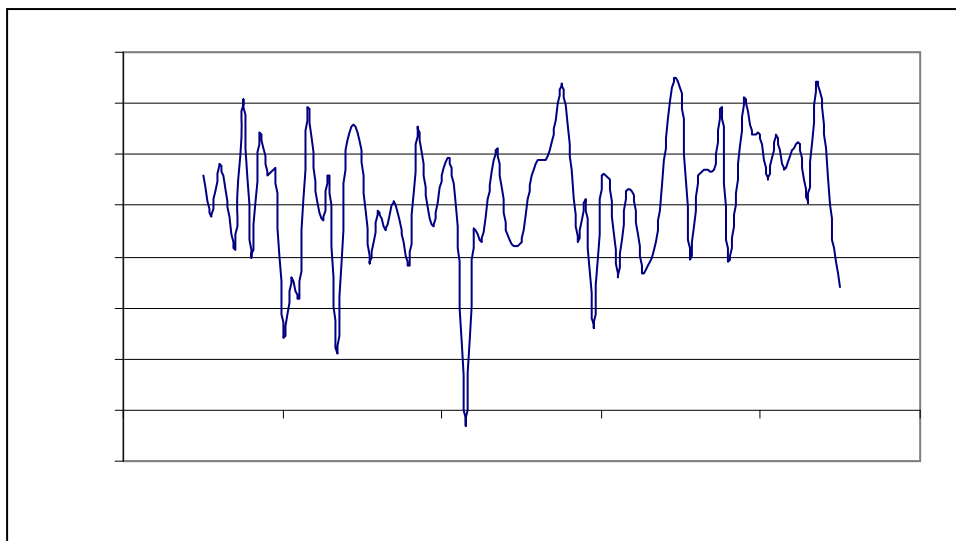


Figure A3.2. Mean winter temperature in central England since 1930

⁴³ Source for pests statistics:
[http://www.forestry.gov.uk/pdf/UpdateddataforchartsC9.pdf/\\$FILE/UpdateddataforchartsC9.pdf](http://www.forestry.gov.uk/pdf/UpdateddataforchartsC9.pdf/$FILE/UpdateddataforchartsC9.pdf)

Figure A3.2 shows the recorded mean winter temperature in central England since 1930. The record shows exceedance of 5.8 to 6 °C every 5 to 8 years. Notwithstanding the lack of evidence for a relationship between mean winter temperature and pest damage (Figure A3.1), it was used in response function construction following its identification as important for controlling populations (Forest Research, 2010a, 2010b). The qualitative response function for FO1b, forest extent affected by green spruce aphid, is given in Table A3.5. It was assumed that a baseline of 10% of current woodland extent in the UK is affected now. Ray *et al.* (2008a) suggested *Elatobium* outbreaks occur every 5 to 8 years: in the past 50 years the average winter temperature has approached 6°C every 5 to 8 years. This was therefore taken to be the threshold for optimum spread of the pest. Current winter average temperature is just over 4°C. Thus a potential increase in outbreaks could occur with a temperature increase just less than 2°C. However, most spruce forest is in the Scottish uplands (see Table A3.6) and the current mean winter temperature for Scotland is around 2°C, so a 4°C increase in mean winter temperature in Scotland would see the conditions for optimum spread of the pest being reached.

The model between winter temperature and *Elatobium* outbreak is not supported by detailed analysis and is not built on robust evidence such as from experimentation. In the absence of such evidence, the suggested relationship is used at present to give an indication of the potential magnitude of impact, albeit with high uncertainty.

Table A3.5. Response Function for FO1b: Forest extent affected by green spruce aphid. The numbers in the table are percentage likelihood scores based on expert judgement input

Magnitude class	Estimated change in metric (response can span classes)							Class value	
very high	0	0	0	0	0	0	10	All spruce forests affected: >700 thousand hectares	5
high	0	0	0	0	10	10	80	> 400 thousand	4
medium	0	0	10	10	80	80	10	>200 thousand	3
low	0	11	80	80	10	10	0	> 100 thousand	2
very low	100	89	10	10	0	0	0	Baseline: current area (70K) of spruce forest affected.	1
	0	1	2	3	4	5	6		
Change in mean winter temperature degrees celsius									

Table A3.6. Spruce forest extent ('000 hectares). Source: Forestry Commission (2010)⁴⁴

Thousand hectares of forest extent				
	England	Wales	Scotland	GB
Sitka spruce	80	84	528	692
Norway spruce	32	11	35	78
	112	95	563	770

Tables A3.7 and A3.8 below show the results from applying the response function for the spread of green spruce aphid (FO1b) to the UKCP09 data. The data should only be used as an indicative picture of the relative risk in each region.

Since the response function for green spruce aphid relates increasing mean winter temperature with increasing prevalence of the pest, regions with the highest mean winter temperatures are most at risk and regions with the biggest change between

⁴⁴ Forestry Statistics 2010 only includes data for Great Britain. Data for Northern Ireland are therefore not available.

baseline temperatures and projected temperatures are likely to see the greatest change in the level of risk. The main differences in these results are borne out in Scotland, where lower winter temperatures translate to less risk of exposure to the pest than other parts of the UK, and in south-east England, where the higher winter temperatures translate to a greater risk of exposure.

Table A3.7. Most likely magnitude of impact of green spruce aphid on forests from projected change in mean winter temperature

Region	2020s			2050s			2080s			Emission Scenario
	p10	p50	p90	p10	p50	p90	p10	p50	p90	
Channel Islands				very low	very low	low	very low	low	low	Low Emission
East Midlands				very low	very low	low	very low	low	low	
East of England				very low	very low	low	very low	low	low	
Eastern Scotland				very low	very low	low	very low	low	low	
Isle of Man				very low	very low	low	very low	low	low	
London				very low	very low	low	very low	low	medium	
North East England				very low	very low	low	very low	low	low	
North West England				very low	very low	low	very low	low	low	
Northern Ireland				very low	very low	low	very low	low	low	
Northern Scotland				very low	very low	low	very low	low	low	
South East England				very low	very low	low	very low	low	medium	
South West England				very low	very low	low	very low	low	low	
Wales				very low	very low	low	very low	low	low	
West Midlands				very low	very low	low	very low	low	low	
Western Scotland				very low	very low	low	very low	low	low	
Yorkshire and Humberside				very low	very low	low	very low	low	low	
Channel Islands	very low	very low	low	very low	low	low	very low	low	medium	Medium Emission
East Midlands	very low	very low	low	very low	low	low	very low	low	medium	
East of England	very low	very low	low	very low	low	low	very low	low	medium	
Eastern Scotland	very low	very low	low	very low	very low	low	very low	low	low	
Isle of Man	very low	very low	very low	very low	very low	low	very low	low	low	
London	very low	very low	low	very low	low	low	very low	low	medium	
North East England	very low	very low	low	very low	very low	low	very low	low	medium	
North West England	very low	very low	low	very low	very low	low	very low	low	medium	
Northern Ireland	very low	very low	very low	very low	very low	low	very low	low	low	
Northern Scotland	very low	very low	very low	very low	very low	low	very low	low	low	
South East England	very low	very low	low	very low	low	low	very low	low	medium	
South West England	very low	very low	low	very low	low	low	very low	low	medium	
Wales	very low	very low	low	very low	low	low	very low	low	medium	
West Midlands	very low	very low	low	very low	low	low	very low	low	medium	
Western Scotland	very low	very low	low	very low	very low	low	very low	low	medium	
Yorkshire and Humberside	very low	very low	low	very low	low	low	very low	low	medium	
Channel Islands				very low	low	low	very low	low	medium	High Emission
East Midlands				very low	low	low	very low	low	medium	
East of England				very low	low	low	very low	low	medium	
Eastern Scotland				very low	very low	low	very low	low	medium	
Isle of Man				very low	very low	low	very low	low	medium	
London				very low	low	low	very low	low	medium	
North East England				very low	low	low	very low	low	medium	
North West England				very low	low	low	very low	low	medium	
Northern Ireland				very low	very low	low	very low	low	medium	
Northern Scotland				very low	very low	low	very low	low	medium	
South East England				very low	low	low	very low	low	medium	
South West England				very low	low	low	very low	low	medium	
Wales				very low	low	low	very low	low	medium	
West Midlands				very low	low	low	very low	low	medium	
Western Scotland				very low	low	low	very low	low	medium	
Yorkshire and Humberside				very low	low	low	very low	low	medium	

Table A3.8. Expected magnitude of impact of green spruce aphid on forests from projected change in mean winter temperature

Region	2020s			2050s			2080s			Emission Scenario
	p10	p50	p90	p10	p50	p90	p10	p50	p90	
Channel Islands				1.09	1.79	2.00	1.36	2.00	2.64	Low Emission
East Midlands				1.10	1.94	2.04	1.45	2.00	2.91	
East of England				1.10	1.97	2.10	1.47	2.00	2.99	
Eastern Scotland				1.07	1.66	2.00	1.11	2.00	2.35	
Isle of Man				1.08	1.62	2.00	1.22	2.00	2.23	
London				1.10	1.98	2.12	1.48	2.00	3.00	
North East England				1.09	1.80	2.00	1.35	2.00	2.66	
North West England				1.09	1.77	2.00	1.33	2.00	2.58	
Northern Ireland				1.06	1.51	2.00	1.15	2.00	2.19	
Northern Scotland				1.06	1.59	2.00	1.10	2.00	2.24	
South East England				1.10	1.97	2.11	1.47	2.00	3.00	
South West England				1.09	1.82	2.00	1.41	2.00	2.71	
Wales				1.09	1.80	2.00	1.39	2.00	2.66	
West Midlands				1.09	1.85	2.00	1.43	2.00	2.77	
Western Scotland				1.09	1.78	2.00	1.34	2.00	2.61	
Yorkshire and Humberside				1.10	1.92	2.04	1.44	2.00	2.90	
Channel Islands	1.06	1.32	2.00	1.15	2.00	2.15	1.53	2.00	3.00	Medium Emission
East Midlands	1.06	1.39	2.00	1.18	2.00	2.40	1.60	2.00	3.00	
East of England	1.06	1.41	2.00	1.20	2.00	2.46	1.64	2.05	3.00	
Eastern Scotland	1.02	1.18	2.00	1.07	1.74	2.00	1.10	2.00	2.79	
Isle of Man	1.04	1.18	1.84	1.10	1.78	2.00	1.26	2.00	2.70	
London	1.06	1.42	2.00	1.21	2.00	2.48	1.64	2.07	3.00	
North East England	1.05	1.31	2.00	1.11	1.99	2.14	1.42	2.00	3.00	
North West England	1.05	1.29	2.00	1.11	1.96	2.07	1.39	2.00	3.00	
Northern Ireland	1.05	1.20	1.82	1.09	1.75	2.00	1.24	2.00	2.69	
Northern Scotland	1.02	1.15	1.96	1.07	1.69	2.00	1.09	2.00	2.65	
South East England	1.06	1.42	2.00	1.21	2.00	2.47	1.63	2.05	3.00	
South West England	1.06	1.36	2.00	1.19	2.00	2.23	1.59	2.00	3.00	
Wales	1.06	1.34	2.00	1.17	2.00	2.17	1.56	2.00	3.00	
West Midlands	1.06	1.37	2.00	1.21	2.00	2.25	1.60	2.00	3.00	
Western Scotland	1.05	1.30	2.00	1.11	1.97	2.09	1.41	2.00	3.00	
Yorkshire and Humberside	1.06	1.38	2.00	1.18	2.00	2.38	1.59	2.00	3.00	
Channel Islands				1.31	2.00	2.44	1.89	2.32	3.09	High Emission
East Midlands				1.42	2.00	2.79	1.92	2.62	3.61	
East of England				1.44	2.00	2.85	1.95	2.69	3.73	
Eastern Scotland				1.08	1.88	2.13	1.22	2.00	3.00	
Isle of Man				1.11	1.94	2.02	1.60	2.00	3.00	
London				1.45	2.00	2.86	1.97	2.71	3.74	
North East England				1.22	2.00	2.40	1.79	2.20	3.01	
North West England				1.20	2.00	2.36	1.75	2.15	3.00	
Northern Ireland				1.10	1.87	2.00	1.63	2.00	3.00	
Northern Scotland				1.07	1.80	2.03	1.19	2.00	3.00	
South East England				1.46	2.00	2.86	1.96	2.70	3.75	
South West England				1.35	2.00	2.50	1.93	2.41	3.22	
Wales				1.33	2.00	2.44	1.91	2.36	3.14	
West Midlands				1.37	2.00	2.55	1.97	2.45	3.29	
Western Scotland				1.21	2.00	2.37	1.75	2.17	3.00	
Yorkshire and Humberside				1.42	2.00	2.76	1.92	2.61	3.61	

Loss of productivity because of drought

Drought can significantly influence tree health, growth and productivity (e.g. Green *et al.*, 2008; Read *et al.*, 2009). Ultimately, drought can cause tree mortality, often when in combination with other stresses such as pests and pathogens (Read *et al.*, 2009). It is recognised, however, that the relationship between drought and productivity is complex as drought-related reduction in growth rate may result in higher quality timber (which could be better for construction uses) because of the slower growth of the tree.

The response function for FO2 was based on the relationship between soil moisture deficit (as an indicator of dry conditions) to the proportion of severely defoliated trees as measured in annual Forest Condition Surveys in south and east England (Hendry *et al.*, 2005), published as Figure 4.9 in the Read Report (Read *et al.*, 2009), and reproduced in Figure A3.3 and Table A3.9 below.

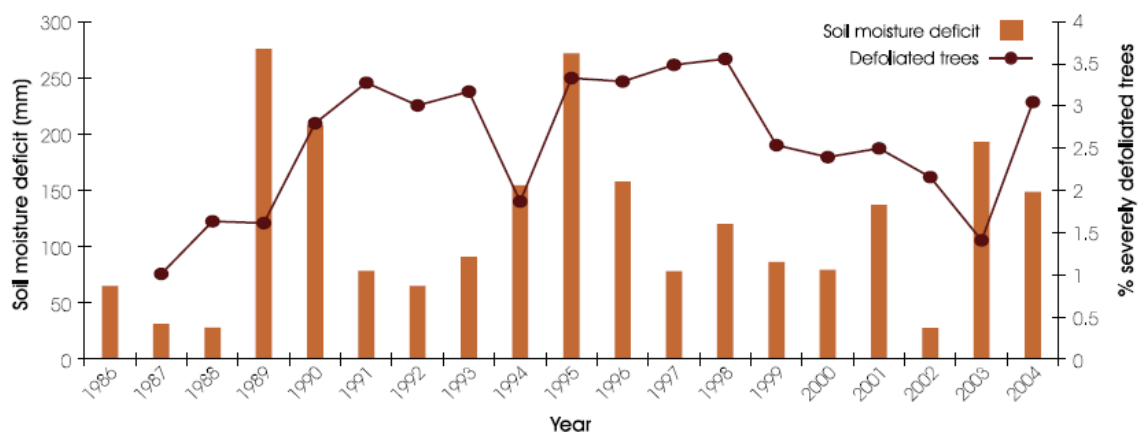


Figure A3.3. Comparison between the proportion of severely defoliated trees and soil moisture deficit between 1986 and 2004. Proportion of defoliated trees representative of all five species (oak, beech, Scots pine, Sitka spruce, Norway spruce) in south and east England from the Forest Condition Survey (Hendry *et al.*, 2005) and soil moisture deficit calculated for the climatological station at Alice Holt, Surrey. From Read *et al.* (2009).

Table A3.9. Comparison between the proportion of severely defoliated trees and soil moisture deficit between 1986 and 2004. Data from Read *et al.* (2009)

Date	SMD (mm)	% severely defoliated trees
1986	69	1.0
1987	31	1.7
1988	28	1.7
1989	281	2.8
1990	213	3.3
1991	19	3.1
1992	17	3.3
1993	94	2.0
1994	156	3.4
1995	278	3.4
1996	163	3.6
1997	81	3.7
1998	125	2.6
1999	88	2.5
2000	81	2.5
2001	138	1.8
2002	28	1.4
2003	197	3.1
2004	150	3.1

The colour coding of groups of figures in Table A3.9 shows groups of similar soil moisture deficit and percentage defoliation. As explained in the Read Report, an increase in soil moisture deficit in one year can have an impact on defoliation for the following three to four years. The coloured groupings in Table A3.9 are slightly more irregular; high soil moisture deficits over a period of two years in 1989-1990 resulted in higher defoliation over four years (1990-1993) because of the magnitude of soil moisture deficit, whilst a three year recovery in soil moisture deficit from 1991-1993 resulted in only one year recovery in defoliation (1994) before another episode of high soil moisture deficits resulted in higher defoliation again. The irregular groupings are therefore associated with the irregular occurrence of drier years. For each grouping of soil moisture deficit and percentage defoliation, the average soil moisture deficit can be associated with the average defoliation for the group. The series of data pairs can be used to build a response function to relate soil moisture deficit to defoliation. This was carried out for a derived climate variable 'relative aridity' (using data from the CCRA water sector analysis, Rance *et al.*, 2012) and for potential soil moisture deficit (PSMD). There are limitations related to use of potential soil moisture deficit, which uses figures calculated for the CCRA agriculture sector (Knox *et al.*, 2012) and may have limited applicability for forest areas.

The response functions to relate the climate variables (PSMD and aridity) to productivity (yield) have been developed using the percentage of severely defoliated trees in a region as an indicator of drought conditions. A factor of four is used to scale percentage defoliated trees to percentage yield reduction. The response functions for relating percentage defoliation and potential yield loss to potential soil moisture deficit and aridity are given in Figure A3.4 and Figure A3.5, based on the groupings of soil moisture deficit, defoliation and yield loss.

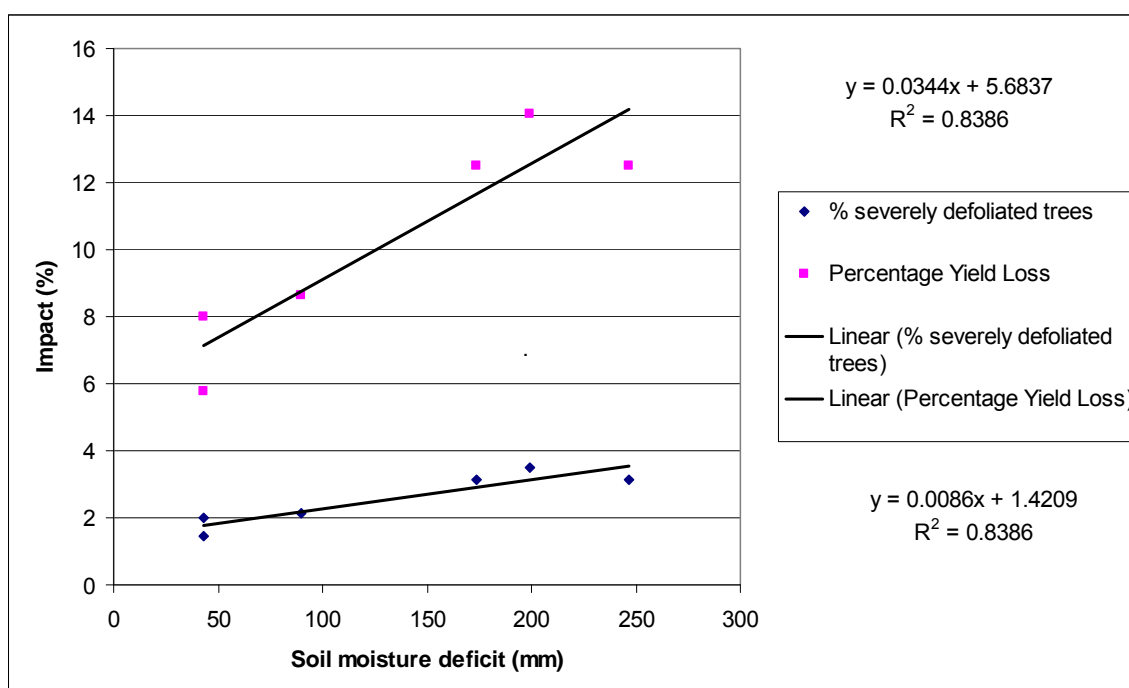


Figure A3.4. Response functions for FO2: Drought impact relationship with potential soil moisture deficit

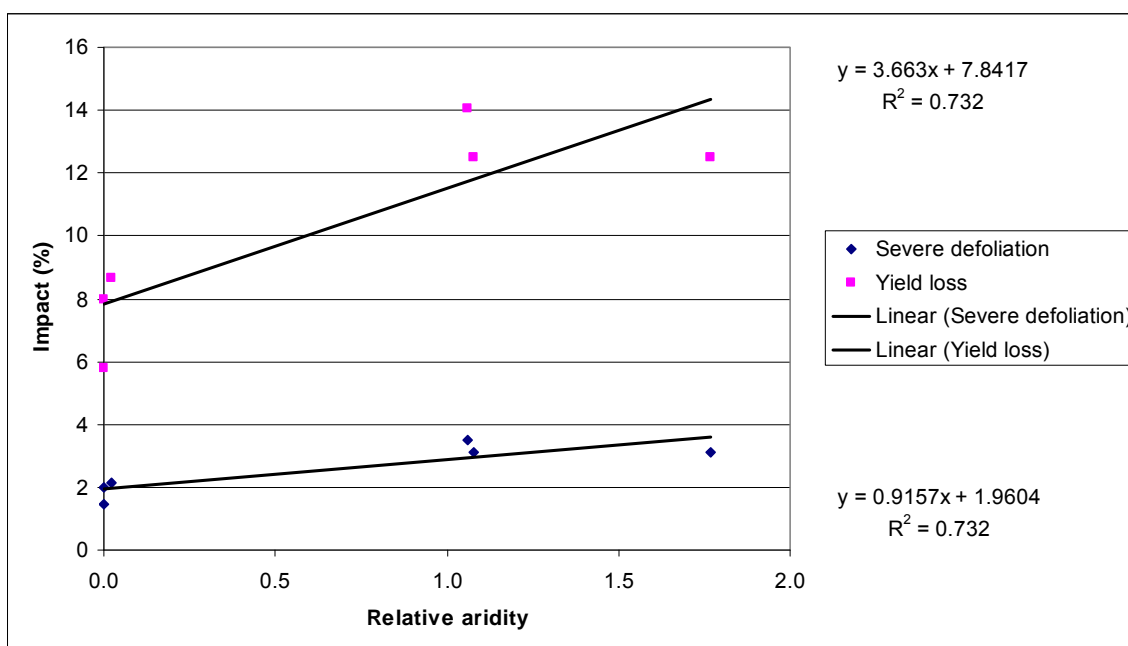


Figure A3.5. Response functions for FO2: Drought impact relationship with relative aridity index

The main limitations associated with these response functions include:

- In some regions, the positive effects of rising accumulated temperature and CO₂ concentrations on productivity would far outstrip any negative impacts of drought. In north Scotland, the apparent reduction in yield because of drought is likely to be replaced by a significant increase in productivity if all climatic factors are taken into account.
- There is limited strength of analysis in the Read Report, Figure 4.9, which provides the basis of this assessment.
- Defoliation does not account for all of potential yield loss and the scaling factor applied is based on expert judgement.
- PSMD has been calculated at local scale for the agriculture sector (representative 25km grid squares in each UKCP09 region) and is applied here to forest areas at the UKCP09 regional scale.
- The calculations of aridity do not pick up potentially significant local spatial differences in precipitation.
- PSMD and aridity factors show general dryness of conditions (i.e. a shifting baseline) and do not capture extreme drought events.
- Projections of area affected does not account for adaptation, e.g. choice of more suitable/less vulnerable species or variety upon commercial felling and replanting.
- The analysis does not take into account the reduction in yield that would be expected if there is an increase in pest and pathogen damage/mortality directly because of drought stress in the host tree.

Table A3.10 show the calculations of statistics used in the regression for developing the response functions.

Table A3.10. Calculations for average aridity, soil moisture deficit, percentage defoliation and percentage yield loss for groupings of related years

Date	Relative Aridity	SMD (mm)	% severely defoliated trees	% yield loss	Av aridity	Av SMD (mm)	Av % defoliated	Av % yield loss
1986	0	68.75			0	42.70833	1.44	5.78
1987	0	31.25	1.00	4.000				
1988	0	28.125	1.67	6.667				
1989	1.15	281.25	1.67	6.667	1.08	246.875	3.13	12.500
1990	1.35	212.5	2.83	11.333				
1991	0.74	19.25	3.33	13.333	0	43.25	2.00	8.00
1992	0	16.75	3.08	12.333				
1993	0	93.75	3.25	13.000				
1994	0	156.25	2.00	8.000	1.06	198.9583	3.51	14.042
1995	1.27	278.125	3.42	13.667				
1996	0.71	162.5	3.38	13.500				
1997	1.2	81.25	3.58	14.333	0.022	90.10417	2.16	8.63
1998	0	125	3.67	14.667				
1999	0.11	87.5	2.58	10.333				
2000	0	81.25	2.46	9.833				
2001	0	137.5	2.54	10.167				
2002	0	28.125	1.79	7.167				
2003	1.77	196.875	1.42	5.667	1.77	173.4375	3.13	12.50
2004		150	3.13	12.500				

The four tables below give results for the potential impact of drought on UK forests, based on the response function developed. The response function draws a direct relationship between climate variables and tree defoliation and this is used to estimate the impact on productivity. The results below are given for both the proportion of severely defoliated trees and the percentage yield loss. As explained above, both soil moisture deficit and aridity were used as alternative climate variables for response functions; the results for both are presented below and discussion on the comparison of results is given in the main text.

Table A3.11. Percentage of severely defoliated trees due to drought, based on the response function relationship with potential soil moisture deficit

% severely defoliated trees

$$y = 0.0086 \cdot \text{PSMD} + 1.4209$$

0.0086
1.4209

	Baseline	2020s			2050s			2080s			Emissions
		p10	p50	p90	p10	p50	p90	p10	p50	p90	
Wales					2.55	3.57	4.71	2.74	3.82	5.11	Low
Western Scotland					2.67	3.57	4.65	2.86	3.89	5.17	
Northern Scotland					2.49	3.25	4.17	2.60	3.46	4.51	
Eastern Scotland					2.75	3.70	4.85	2.87	3.92	5.21	
South West England					2.66	3.67	4.85	2.84	3.89	5.19	
North West England					2.43	3.35	4.34	2.59	3.54	4.65	
West Midlands					2.74	3.82	5.07	2.87	3.96	5.30	
North East England					2.79	3.84	5.05	2.96	4.04	5.35	
South East England					2.86	4.14	5.59	3.05	4.34	5.84	
Yorkshire and Humberside					2.77	3.83	5.03	2.90	3.99	5.28	
East Midlands					2.99	4.27	5.71	3.14	4.45	5.96	
East of England					2.88	4.10	5.48	3.01	4.27	5.68	
Wales	2.53	2.19	3.11	4.11	2.89	4.05	5.38	3.26	4.56	6.11	Medium
Western Scotland	2.33	2.25	3.05	3.99	2.88	3.87	5.07	3.37	4.65	6.22	
Northern Scotland	2.44	2.18	2.91	3.74	2.61	3.41	4.39	2.90	3.87	5.06	
Eastern Scotland	2.66	2.36	3.26	4.27	2.94	3.97	5.22	3.26	4.47	5.96	
South West England	2.86	2.33	3.37	4.50	2.89	3.99	5.28	3.18	4.33	5.76	
North West England	2.53	2.12	2.99	3.90	2.64	3.63	4.71	2.93	4.03	5.30	
West Midlands	3.05	2.38	3.48	4.69	2.92	4.03	5.36	3.14	4.29	5.71	
North East England	2.89	2.43	3.41	4.50	3.00	4.10	5.38	3.31	4.52	5.96	
South East England	3.40	2.63	3.82	5.12	3.15	4.35	5.69	3.45	4.67	6.11	
Yorkshire and Humberside	3.01	2.41	3.47	4.58	2.96	4.05	5.27	3.22	4.36	5.72	
East Midlands	3.41	2.60	3.89	5.24	3.20	4.48	5.93	3.48	4.79	6.36	
East of England	3.43	2.55	3.82	5.12	3.05	4.26	5.62	3.31	4.51	5.96	
Wales					2.90	4.09	5.45	3.68	5.29	7.19	High
Western Scotland					3.05	4.12	5.38	3.96	5.48	7.46	
Northern Scotland					2.71	3.56	4.56	3.25	4.35	5.77	
Eastern Scotland					3.02	4.08	5.32	3.67	5.02	6.77	
South West England					2.94	4.01	5.23	3.46	4.72	6.27	
North West England					2.70	3.69	4.82	3.27	4.54	6.06	
West Midlands					2.96	4.06	5.31	3.42	4.64	6.16	
North East England					3.06	4.16	5.44	3.70	5.02	6.67	
South East England					3.29	4.42	5.71	3.73	5.02	6.54	
Yorkshire and Humberside					3.06	4.09	5.26	3.52	4.76	6.22	
East Midlands					3.32	4.54	5.92	3.78	5.19	6.83	
East of England					3.17	4.31	5.61	3.53	4.81	6.29	

Table A3.12. Percentage forest productivity yield loss due to drought, based on the response function relationship with potential soil moisture deficit

% Yield Loss

$$y = 0.0043 \cdot \text{PSMD} + 0.8386$$

0.0344

5.6837

	Baseline	2020s			2050s			2080s			Emissions
		p10	p50	p90	p10	p50	p90	p10	p50	p90	
Wales					10.21	14.27	18.84	10.97	15.30	20.44	Low
Western Scotland					10.68	14.29	18.60	11.43	15.57	20.68	
Northern Scotland					9.94	13.02	16.70	10.41	13.83	18.04	
Eastern Scotland					10.99	14.82	19.40	11.49	15.68	20.85	
South West England					10.63	14.69	19.40	11.36	15.55	20.75	
North West England					9.70	13.40	17.35	10.37	14.15	18.62	
West Midlands					10.96	15.26	20.28	11.49	15.85	21.21	
North East England					11.15	15.37	20.19	11.85	16.17	21.42	
South East England					11.45	16.57	22.36	12.20	17.37	23.34	
Yorkshire and Humberside					11.06	15.30	20.13	11.59	15.97	21.13	
East Midlands					11.97	17.06	22.84	12.55	17.79	23.84	
East of England					11.54	16.40	21.91	12.05	17.06	22.72	
Wales	10.13	8.77	12.45	16.44	11.58	16.20	21.53	13.04	18.26	24.43	Medium
Western Scotland	9.32	9.00	12.19	15.97	11.50	15.47	20.27	13.49	18.59	24.89	
Northern Scotland	9.74	8.72	11.66	14.95	10.42	13.65	17.56	11.60	15.47	20.24	
Eastern Scotland	10.65	9.43	13.04	17.09	11.75	15.88	20.89	13.05	17.87	23.82	
South West England	11.42	9.30	13.47	18.02	11.57	15.94	21.13	12.73	17.30	23.05	
North West England	10.11	8.48	11.95	15.58	10.57	14.51	18.86	11.73	16.12	21.18	
West Midlands	12.22	9.54	13.92	18.77	11.67	16.11	21.42	12.56	17.17	22.82	
North East England	11.56	9.72	13.64	18.01	11.99	16.41	21.51	13.26	18.06	23.83	
South East England	13.60	10.51	15.30	20.46	12.59	17.40	22.78	13.80	18.66	24.46	
Yorkshire and Humberside	12.05	9.63	13.87	18.33	11.85	16.18	21.09	12.87	17.43	22.88	
East Midlands	13.63	10.40	15.57	20.97	12.80	17.93	23.73	13.94	19.16	25.45	
East of England	13.74	10.19	15.26	20.50	12.21	17.04	22.49	13.25	18.03	23.82	
Wales					11.61	16.37	21.78	14.72	21.15	28.74	High
Western Scotland					12.20	16.47	21.54	15.83	21.94	29.84	
Northern Scotland					10.85	14.23	18.25	12.99	17.39	23.08	
Eastern Scotland					12.10	16.30	21.28	14.66	20.07	27.07	
South West England					11.76	16.03	20.92	13.84	18.88	25.06	
North West England					10.82	14.77	19.26	13.07	18.15	24.25	
West Midlands					11.84	16.22	21.22	13.67	18.58	24.65	
North East England					12.25	16.62	21.77	14.79	20.06	26.69	
South East England					13.17	17.66	22.85	14.93	20.06	26.14	
Yorkshire and Humberside					12.25	16.38	21.04	14.06	19.06	24.90	
East Midlands					13.29	18.15	23.66	15.10	20.74	27.33	
East of England					12.68	17.24	22.43	14.14	19.22	25.17	

Table A3.13. Percentage of severely defoliated trees due to drought, based on the response function relationship with aridity index

UKCP09 BASINS

% severely defoliated trees

$$y = m \cdot \text{relative aridity} + c$$

m 0.725
c 2.2609

Table 2

		PROJECTED % defoliation due to drought								
		Low Emission			Medium Emission			High Emission		
		p10 (wet)	p50 (mid)	p90 (dry)	p10 (wet)	p50 (mid)	p90 (dry)	p10 (wet)	p50 (mid)	p90 (dry)
Anglian	2020s	2.63	2.98	3.35	2.61	2.99	3.39	2.63	2.99	3.37
	2050s	2.88	3.39	3.97	3.01	3.56	4.18	3.14	3.71	4.36
	2080s	3.04	3.66	4.36	3.36	4.05	4.89	3.65	4.49	5.47
Dee	2020s	2.60	2.97	3.38	2.58	3.00	3.44	2.60	2.99	3.40
	2050s	2.88	3.39	3.97	3.00	3.57	4.23	3.12	3.73	4.43
	2080s	3.05	3.66	4.39	3.35	4.08	4.99	3.66	4.54	5.60
Humber	2020s	2.64	3.00	3.38	2.62	3.00	3.40	2.65	3.01	3.40
	2050s	2.91	3.42	4.01	3.03	3.57	4.19	3.18	3.75	4.40
	2080s	3.09	3.70	4.42	3.37	4.08	4.92	3.70	4.55	5.55
North West England	2020s	2.60	3.01	3.45	2.60	3.03	3.48	2.63	3.03	3.45
	2050s	2.91	3.50	4.13	3.00	3.60	4.26	3.09	3.73	4.46
	2080s	3.08	3.74	4.52	3.34	4.12	5.03	3.59	4.51	5.61
Northumbria	2020s	2.67	3.05	3.47	2.66	3.05	3.48	2.68	3.04	3.45
	2050s	2.96	3.49	4.11	3.06	3.61	4.26	3.16	3.76	4.47
	2080s	3.16	3.78	4.54	3.42	4.15	5.03	3.72	4.57	5.64
Severn	2020s	2.62	2.97	3.37	2.60	2.99	3.42	2.61	2.98	3.39
	2050s	2.88	3.39	3.98	3.01	3.56	4.23	3.12	3.73	4.43
	2080s	3.05	3.65	4.38	3.35	4.08	4.98	3.67	4.53	5.60
Solway	2020s	2.67	3.04	3.46	2.66	3.04	3.47	2.67	3.04	3.46
	2050s	2.97	3.48	4.10	3.06	3.61	4.27	3.17	3.76	4.46
	2080s	3.13	3.75	4.53	3.39	4.12	5.03	3.69	4.55	5.67
South East England	2020s	2.59	2.94	3.32	2.63	3.01	3.41	2.64	2.99	3.37
	2050s	2.83	3.33	3.90	3.05	3.59	4.20	3.19	3.74	4.38
	2080s	3.01	3.61	4.30	3.42	4.12	4.94	3.76	4.60	5.58
South West England	2020s	2.62	2.98	3.38	2.61	3.01	3.44	2.62	3.00	3.40
	2050s	2.89	3.40	4.00	3.02	3.59	4.26	3.13	3.75	4.45
	2080s	3.07	3.67	4.41	3.38	4.11	5.02	3.68	4.56	5.63
Thames	2020s	2.63	2.97	3.33	2.61	2.98	3.36	2.64	2.98	3.35
	2050s	2.87	3.37	3.93	3.00	3.52	4.13	3.13	3.68	4.31
	2080s	3.04	3.63	4.33	3.34	4.01	4.83	3.63	4.45	5.41
Western Wales	2020s	2.59	2.99	3.43	2.60	3.00	3.43	2.59	3.01	3.47
	2050s	2.90	3.46	4.10	3.01	3.60	4.28	3.08	3.75	4.50
	2080s	3.06	3.72	4.50	3.36	4.13	5.05	3.62	4.58	5.72
Argyll	2020s	2.63	3.08	3.54	2.64	3.07	3.53	2.67	3.07	3.50
	2050s	2.91	3.53	4.21	3.00	3.61	4.34	3.09	3.76	4.52
	2080s	3.08	3.79	4.62	3.30	4.11	5.08	3.55	4.51	5.66
Clyde	2020s	2.70	3.09	3.52	2.69	3.08	3.53	2.69	3.08	3.52
	2050s	3.01	3.55	4.20	3.10	3.68	4.36	3.22	3.84	4.59
	2080s	3.17	3.83	4.64	3.44	4.22	5.17	3.76	4.68	5.84
Forth	2020s	2.64	3.06	3.52	2.65	3.07	3.54	2.68	3.08	3.50
	2050s	2.96	3.57	4.25	3.06	3.68	4.38	3.16	3.83	4.60
	2080s	3.14	3.84	4.66	3.42	4.24	5.19	3.71	4.66	5.82
North East Scotland	2020s	2.64	3.02	3.44	2.63	3.02	3.44	2.65	3.02	3.42
	2050s	2.91	3.44	4.05	2.97	3.52	4.16	3.08	3.65	4.34
	2080s	3.10	3.71	4.45	3.31	4.01	4.87	3.55	4.36	5.39
North Highland	2020s	2.66	3.06	3.48	2.66	3.05	3.47	2.69	3.04	3.45
	2050s	2.92	3.48	4.11	3.00	3.57	4.24	3.11	3.71	4.43
	2080s	3.10	3.76	4.53	3.32	4.06	4.98	3.58	4.44	5.53
Orkney and Shetland	2020s	2.62	3.08	3.56	2.64	3.07	3.54	2.67	3.08	3.52
	2050s	2.91	3.56	4.27	2.98	3.63	4.38	3.08	3.78	4.57
	2080s	3.05	3.80	4.67	3.26	4.13	5.16	3.49	4.54	5.74
Tay	2020s	2.63	3.03	3.46	2.63	3.03	3.46	2.65	3.03	3.45
	2050s	2.93	3.47	4.08	2.99	3.54	4.19	3.09	3.68	4.37
	2080s	3.10	3.74	4.49	3.32	4.05	4.91	3.54	4.40	5.46
West Highland	2020s	2.65	3.10	3.58	2.65	3.09	3.57	2.69	3.09	3.54
	2050s	2.94	3.57	4.27	3.02	3.65	4.39	3.12	3.80	4.58
	2080s	3.11	3.83	4.69	3.32	4.16	5.18	3.57	4.57	5.75
North Western Ireland	2020s	2.71	3.09	3.49	2.70	3.11	3.54	2.70	3.08	3.49
	2050s	3.01	3.55	4.15	3.15	3.72	4.38	3.25	3.86	4.59
	2080s	3.21	3.85	4.64	3.54	4.30	5.21	3.90	4.81	5.91
Neagh Bann	2020s	2.73	3.10	3.50	2.71	3.11	3.53	2.71	3.08	3.49
	2050s	3.01	3.54	4.15	3.16	3.72	4.38	3.27	3.87	4.59
	2080s	3.23	3.87	4.64	3.57	4.31	5.22	3.94	4.83	5.91
North Eastern Ireland	2020s	2.69	3.08	3.52	2.68	3.08	3.53	2.71	3.08	3.50
	2050s	2.99	3.56	4.21	3.10	3.68	4.37	3.20	3.84	4.59
	2080s	3.19	3.86	4.66	3.46	4.24	5.18	3.79	4.67	5.81
Tweed	2020s	2.72	3.14	3.61	2.71	3.14	3.63	2.74	3.14	3.59
	2050s	3.05	3.65	4.36	3.16	3.79	4.52	3.29	3.95	4.75
	2080s	3.26	3.97	4.85	3.55	4.39	5.40	3.90	4.85	6.06

Table A3.13. Percentage forest productivity yield loss due to drought, based on the response function relationship with aridity index

UKCP09 BASINS

% yield loss

$y = m \cdot \text{relative aridity} + c$

m 2.8998

c 9.0435

Table 2

		PROJECTED % loss of yield due to drought								
		Low Emission			Medium Emission			High Emission		
		p10 (wet)	p50 (mid)	p90 (dry)	p10 (wet)	p50 (mid)	p90 (dry)	p10 (wet)	p50 (mid)	p90 (dry)
Anglian	2020s	10.52	11.90	13.42	10.42	11.97	13.57	10.50	11.97	13.48
	2050s	11.50	13.55	15.87	12.02	14.22	16.71	12.56	14.85	17.45
	2080s	12.18	14.64	17.43	13.43	16.20	19.57	14.61	17.96	21.87
Dee	2020s	10.39	11.90	13.50	10.33	11.99	13.74	10.41	11.94	13.59
	2050s	11.53	13.55	15.83	12.00	14.28	16.93	12.47	14.91	17.73
	2080s	12.21	14.63	17.54	13.41	16.32	19.95	14.62	18.16	22.40
Humber	2020s	10.57	12.00	13.52	10.47	12.00	13.61	10.58	12.04	13.60
	2050s	11.64	13.70	16.03	12.13	14.29	16.74	12.70	15.00	17.60
	2080s	12.34	14.79	17.66	13.50	16.32	19.70	14.78	18.21	22.21
North West England	2020s	10.41	12.03	13.81	10.42	12.12	13.91	10.54	12.11	13.80
	2050s	11.63	14.00	16.54	12.01	14.42	17.06	12.37	14.93	17.85
	2080s	12.32	14.97	18.09	13.36	16.50	20.11	14.37	18.03	22.43
Northumbria	2020s	10.67	12.20	13.86	10.64	12.18	13.90	10.73	12.18	13.80
	2050s	11.82	13.98	16.43	12.23	14.45	17.03	12.66	15.06	17.88
	2080s	12.62	15.13	18.18	13.67	16.60	20.12	14.90	18.28	22.54
Severn	2020s	10.46	11.89	13.46	10.41	11.95	13.67	10.45	11.93	13.55
	2050s	11.53	13.56	15.92	12.04	14.26	16.92	12.48	14.92	17.70
	2080s	12.22	14.61	17.54	13.40	16.32	19.91	14.67	18.13	22.41
Solway	2020s	10.66	12.17	13.86	10.63	12.17	13.89	10.66	12.16	13.82
	2050s	11.88	13.94	16.39	12.25	14.44	17.09	12.66	15.03	17.84
	2080s	12.51	15.02	18.11	13.55	16.50	20.14	14.76	18.21	22.66
South East England	2020s	10.38	11.76	13.28	10.54	12.02	13.62	10.54	11.96	13.49
	2050s	11.31	13.32	15.59	12.18	14.37	16.81	12.74	14.96	17.52
	2080s	12.05	14.44	17.20	13.68	16.46	19.78	15.05	18.38	22.33
South West England	2020s	10.47	11.93	13.51	10.43	12.03	13.78	10.49	11.99	13.58
	2050s	11.54	13.60	15.98	12.09	14.35	17.03	12.53	14.98	17.79
	2080s	12.29	14.68	17.65	13.52	16.42	20.08	14.71	18.22	22.52
Thames	2020s	10.53	11.86	13.32	10.43	11.90	13.44	10.54	11.91	13.39
	2050s	11.50	13.47	15.71	12.01	14.10	16.50	12.51	14.73	17.25
	2080s	12.15	14.54	17.30	13.35	16.05	19.32	14.54	17.81	21.63
Western Wales	2020s	10.35	11.96	13.70	10.40	12.00	13.72	10.34	12.04	13.86
	2050s	11.58	13.86	16.42	12.04	14.39	17.10	12.34	14.99	17.99
	2080s	12.26	14.89	18.01	13.43	16.54	20.21	14.46	18.32	22.88
Argyll	2020s	10.52	12.30	14.17	10.56	12.29	14.12	10.70	12.28	14.02
	2050s	11.65	14.13	16.86	12.01	14.43	17.36	12.38	15.03	18.09
	2080s	12.34	15.16	18.47	13.21	16.45	20.34	14.19	18.04	22.63
Clyde	2020s	10.80	12.35	14.09	10.75	12.33	14.13	10.77	12.32	14.07
	2050s	12.05	14.20	16.78	12.42	14.72	17.44	12.88	15.35	18.37
	2080s	12.68	15.33	18.56	13.77	16.89	20.68	15.04	18.72	23.38
Forth	2020s	10.57	12.25	14.06	10.59	12.29	14.16	10.72	12.31	14.02
	2050s	11.84	14.29	16.99	12.23	14.74	17.54	12.65	15.32	18.40
	2080s	12.55	15.36	18.64	13.69	16.95	20.77	14.83	18.63	23.27
North East Scotland	2020s	10.56	12.09	13.76	10.52	12.07	13.75	10.59	12.07	13.68
	2050s	11.65	13.75	16.20	11.89	14.09	16.65	12.31	14.60	17.36
	2080s	12.39	14.85	17.78	13.23	16.03	19.47	14.18	17.43	21.56
North Highland	2020s	10.64	12.24	13.93	10.65	12.19	13.87	10.75	12.18	13.81
	2050s	11.68	13.91	16.43	12.01	14.28	16.97	12.44	14.82	17.71
	2080s	12.42	15.03	18.11	13.29	16.23	19.91	14.33	17.75	22.13
Orkney and Shetland	2020s	10.50	12.32	14.22	10.57	12.29	14.18	10.70	12.32	14.09
	2050s	11.64	14.24	17.09	11.92	14.52	17.54	12.32	15.13	18.28
	2080s	12.19	15.18	18.67	13.03	16.51	20.64	13.97	18.14	22.95
Tay	2020s	10.53	12.12	13.85	10.51	12.11	13.83	10.58	12.13	13.80
	2050s	11.71	13.86	16.30	11.98	14.17	16.77	12.34	14.70	17.48
	2080s	12.41	14.94	17.95	13.27	16.19	19.65	14.15	17.58	21.83
West Highland	2020s	10.58	12.39	14.32	10.62	12.36	14.27	10.75	12.37	14.14
	2050s	11.78	14.27	17.07	12.06	14.59	17.56	12.46	15.20	18.32
	2080s	12.42	15.31	18.74	13.28	16.64	20.70	14.29	18.27	23.01
North Western Ireland	2020s	10.83	12.34	13.96	10.81	12.42	14.15	10.78	12.30	13.94
	2050s	12.04	14.19	16.59	12.60	14.89	17.53	13.00	15.46	18.36
	2080s	12.83	15.41	18.56	14.15	17.21	20.83	15.61	19.23	23.63
Neagh Bann	2020s	10.91	12.39	14.00	10.86	12.44	14.13	10.83	12.33	13.94
	2050s	12.05	14.18	16.62	12.63	14.90	17.52	13.06	15.47	18.38
	2080s	12.91	15.49	18.56	14.26	17.26	20.88	15.78	19.32	23.64
North Eastern Ireland	2020s	10.74	12.33	14.08	10.72	12.32	14.12	10.84	12.34	13.99
	2050s	11.96	14.25	16.86	12.38	14.74	17.46	12.81	15.34	18.37
	2080s	12.77	15.45	18.63	13.86	16.98	20.72	15.15	18.68	23.23
Tweed	2020s	10.89	12.58	14.44	10.86	12.57	14.50	10.96	12.56	14.35
	2050s	12.19	14.60	17.44	12.64	15.14	18.09	13.15	15.80	19.00
	2080s	13.05	15.88	19.39	14.21	17.56	21.60	15.60	19.40	24.25

Change in tree productivity

Forest potential productivity was calculated for the public forest estate in England, Wales and Scotland using information on existing tree species and soil type contained in the Forestry Commission sub-compartment database (Horne and Whitlock, 1984). These data were combined with projections of climatic variables from the UKCIP02 climate change assessment in order to estimate potential Yield Class (YC, $\text{m}^3 \text{y}^{-1} \text{ha}^{-1}$) for each stand of trees from the Ecological Site Classification model (ESC, Pyatt *et al.*, 2001). Yield class is an estimate of the maximum mean annual increment of stem volume per hectare for a particular site during a rotation. For baseline estimates, interpolated climate data to a resolution of 250 m were used, but interpolation to a resolution of 1 km was used for the 2050s and 2080s projections. UKCP09 projections are currently unsuitable for input into ESC as they lack evapotranspiration and wind data. Tables A3.14 and A3.15 give estimated potential YC for baseline, 2050s and 2080s, using UKCIP02 'high' scenarios only for six common broadleaved species and seven common conifers. There is considerable variation in baseline YC between countries and regions and this is exacerbated by the 2050s and 2080s, notably for those species where current suitability is marginal.

Data for the areal extent of each species in each Forestry Commission administrative region taken from the sub-compartment database has been combined with the YC estimates to produce estimates of annual potential yield in $\text{m}^3 \text{yr}^{-1}$ for eight tree species (Chapter 5) by the 2050s and 2080s. These are summarised in Figures 5.2 and 5.3 as change in productivity from baseline (current estimate). Some of the assumptions made in producing these data are discussed in Chapters 4 and 5.

Increased risk of wildfire

The main effect of forest fires is to the wildlife habitats that forests support. Increased risk of wildfire may have a profound effect on these habitats and their species in fire prone areas, potentially resulting in the local species extinction at the expense of those that are more fire-tolerant or can adapt to habitat modification. Wildfires can also increase rates of erosion and have a detrimental effect on water quality, and hence on aquatic ecosystems. Wildfires inevitably impact on forest access by the public, and thus on amenity and recreation.

Table A3.14. Estimated Yield Class (maximum Mean Annual increment in m³ ha⁻¹ yr⁻¹) for commercially important broadleaved tree species on the public forest estate

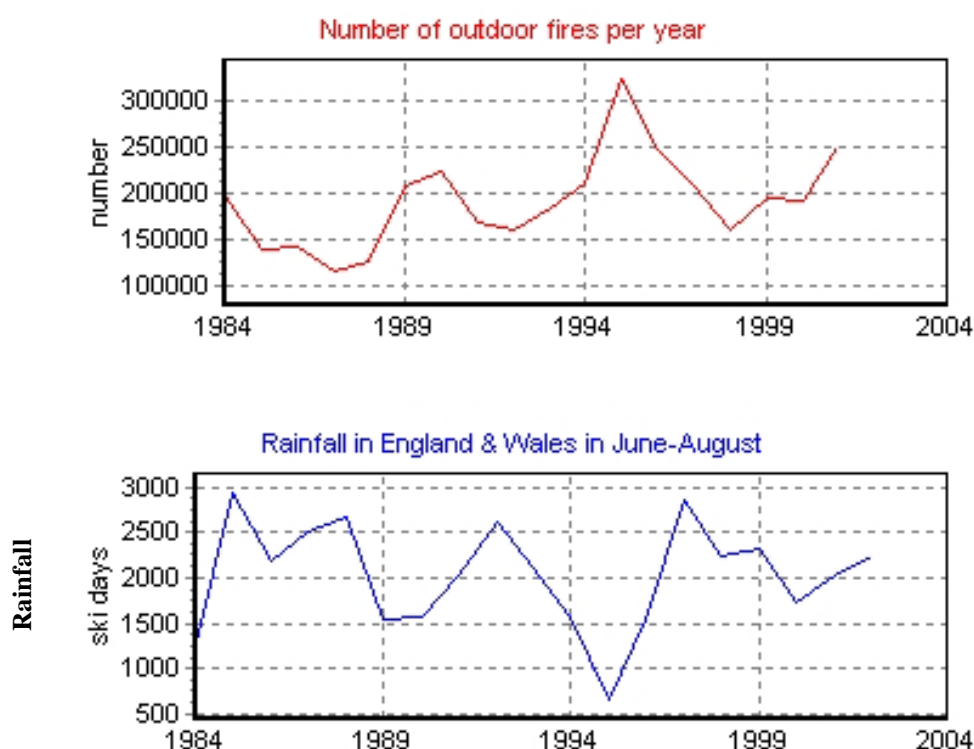
Region	Ash			Beech			Downy birch			Silver birch			Sessile oak			Sycamore		
	Baseline	2050	2080	Baseline	2050	2080	Baseline	2050	2080	Baseline	2050	2080	Baseline	2050	2080	Baseline	2050	2080
<u>GB</u>	7.2	6.6	5.5	6.9	6.0	3.2	5.6	4.8	3.6	6.9	6.1	5.1	5.3	4.8	3.2	7.0	5.9	3.8
<u>England</u>	7.6	6.6	5.2	7.0	5.9	2.8	5.3	3.1	1.0	8.0	6.0	2.7	5.5	4.8	2.8	7.3	5.7	3.2
<u>England - conservancies</u>																		
East England	7.6	5.6	4.7	6.7	4.9	2.8	2.9	1.8	0.3	6.2	4.8	1.8	4.7	4.0	2.7	6.4	3.9	2.0
East Midlands	8.0	6.4	5.1	7.1	5.7	3.5	4.8	2.8	0.8	7.8	5.7	2.8	5.9	4.7	3.1	7.9	5.2	2.9
North East England	7.0	7.3	6.5	5.6	6.1	4.7	6.9	5.8	4.6	7.4	7.5	6.8	4.0	4.3	3.8	6.5	7.2	5.7
North West England	5.0	6.1	6.3	6.5	6.4	5.4	6.6	5.5	4.2	8.4	7.2	6.3	5.1	4.9	4.7	5.8	6.4	5.3
South East England	8.2	7.1	4.9	7.0	5.6	2.1	5.5	2.9	0.1	8.6	5.8	0.9	5.5	5.1	2.3	8.0	5.6	1.8
South West England	7.4	6.8	5.2	7.3	6.3	3.1	6.8	2.9	0.3	9.0	6.2	1.9	6.0	5.0	3.0	8.4	5.8	2.4
West Midlands	7.5	7.0	5.5	7.4	6.5	3.5	5.6	2.4	0.7	8.6	6.1	3.0	5.5	4.4	3.3	7.5	5.3	2.8
Yorkshire and The Humber	6.6	7.1	6.3	6.5	6.8	5.3	5.9	4.0	2.0	7.6	7.0	4.8	4.6	4.6	3.6	7.5	6.7	4.5
<u>Scotland</u>	4.8	5.7	6.6	5.3	5.6	5.6	5.6	5.7	5.2	6.1	6.0	6.4	3.7	4.2	4.3	5.7	6.2	5.8
<u>Scotland - conservancies</u>																		
Central Scotland	5.8	7.3	8.1	5.4	6.0	5.9	6.2	6.3	5.1	6.1	6.6	6.4	4.8	5.6	5.1	5.5	6.5	6.4
Grampian	2.0	2.7	3.3	4.1	4.9	5.2	3.8	3.3	2.8	5.8	6.1	5.8	2.2	3.2	3.6	3.6	4.8	5.2
Highland	3.4	3.8	4.4	4.2	4.1	4.8	5.7	6.0	5.9	5.6	5.8	6.5	3.1	3.7	4.0	4.0	4.5	5.3
Perth and Argyll	4.8	5.9	6.7	5.4	5.4	5.3	5.8	5.8	5.1	6.5	6.0	6.4	3.9	4.2	4.4	6.1	6.1	5.5
South Scotland	6.0	7.0	8.0	6.4	6.9	6.6	6.4	5.9	3.9	7.2	7.4	5.9	4.4	4.9	4.2	6.4	7.0	6.3
<u>Wales</u>	6.8	7.4	6.2	6.8	6.8	4.4	7.1	5.6	2.8	8.1	7.5	4.9	5.3	5.4	4.1	7.8	7.2	3.8
<u>Wales - conservancies</u>																		
North Wales	5.1	6.0	6.1	6.4	6.6	5.6	6.9	6.1	3.9	7.8	7.5	6.2	5.0	5.6	4.8	7.2	7.2	4.8
South Wales	7.4	7.8	6.2	7.0	6.8	3.9	7.3	5.2	2.0	8.3	7.5	3.9	5.4	5.3	3.7	8.1	7.1	3.2

Table A3.15. Estimated Yield Class (maximum Mean Annual increment in m³ ha⁻¹ yr⁻¹) for commercially important conifer tree species on the public forest estate

Region	Douglas fir			European larch			Japanese larch			Lodgepole pine			Norway spruce			Scots pine			Sitka spruce		
	Baseline	2050	2080	Baseline	2050	2080	Baseline	2050	2080	Baseline	2050	2080	Baseline	2050	2080	Baseline	2050	2080	Baseline	2050	2080
GB	12.4	12.4	8.2	6.0	5.2	4.0	8.2	7.8	6.0	9.5	10.5	10.9	12.8	11.8	9.9	7.9	8.4	6.7	14.2	15.5	15.1
England	14.6	13.6	7.2	8.2	5.4	1.7	8.8	4.5	1.9	10.6	11.8	10.6	14.7	10.6	5.6	9.8	8.5	3.3	14.8	14.9	11.9
England - conservancies																					
East England	16.4	14.1	8.4	6.0	1.6	0.1	0.4	0.0	0.0	12.7	11.1	3.9	12.4	2.1	0.2	9.1	7.0	1.5	6.5	4.3	0.4
East Midlands	16.7	14.7	9.0	7.5	3.1	0.8	7.3	4.7	2.3	11.3	12.6	9.9	15.6	3.9	0.3	11.1	9.3	3.5	13.8	15.6	11.8
North East England	9.9	10.8	8.6	7.2	6.8	4.6	8.6	6.5	2.5	9.4	11.1	11.7	12.7	14.7	13.5	8.0	9.0	7.7	14.1	14.5	11.7
North West England	11.5	8.6	8.1	7.3	5.7	6.7	9.8	9.8	9.8	10.3	11.2	11.1	13.4	14.5	14.2	9.4	9.2	6.1	15.0	17.4	18.6
South East England	13.0	11.6	4.0	8.8	4.3	0.1	4.0	0.0	0.0	13.2	9.2	0.0	13.8	6.3	0.1	10.6	7.4	0.1	11.5	4.0	0.0
South West England	15.2	14.7	6.8	9.6	6.4	0.7	10.3	3.4	0.3	12.8	11.6	4.7	17.2	10.4	1.6	9.9	8.2	1.3	18.2	16.1	8.0
West Midlands	16.0	14.3	9.2	8.7	5.8	0.7	9.6	1.1	0.0	13.2	12.7	7.3	17.3	9.0	0.6	11.7	10.7	4.6	14.9	8.3	0.4
Yorkshire and The Humber	12.7	13.6	10.0	7.2	7.2	4.5	8.6	4.6	0.0	12.4	13.7	11.2	14.5	13.8	7.1	8.8	9.6	6.3	15.1	12.0	6.0
Scotland	8.0	8.9	9.1	4.7	4.9	5.1	7.2	7.8	7.4	9.2	10.2	11.0	10.6	11.1	12.0	7.0	8.3	8.4	13.3	14.4	15.7
Scotland - conservancies																					
Central Scotland	8.9	8.5	6.3	6.9	7.6	6.6	7.9	8.4	6.5	10.3	11.3	11.3	12.4	13.8	12.6	8.6	9.3	7.5	12.2	13.3	13.9
Grampian	7.4	9.3	9.9	4.1	4.8	4.7	5.6	6.5	6.0	8.3	10.7	11.7	8.6	10.6	11.7	7.4	9.1	8.8	13.4	14.9	16.7
Highland	5.0	5.5	6.3	4.1	4.2	5.0	6.4	7.0	6.8	9.1	10.1	11.1	8.3	8.7	10.1	6.5	7.9	8.4	13.7	14.6	15.4
Perth and Argyll	9.6	10.0	10.2	4.9	5.1	5.2	7.8	8.2	7.9	9.0	9.4	10.3	11.5	10.6	12.1	7.4	8.7	8.7	14.5	15.8	16.6
South Scotland	11.6	13.1	11.9	6.9	7.1	6.1	8.1	8.8	8.3	10.2	11.1	11.2	12.1	13.4	13.5	7.4	8.1	7.3	0.0	0.0	0.0
Wales	13.3	14.3	9.2	8.8	7.9	5.3	10.2	10.4	6.0	11.0	11.2	9.2	14.5	15.2	12.1	9.2	9.3	5.3	15.3	18.2	17.0
Wales - conservancies																					
North Wales	12.5	14.1	11.7	8.1	8.2	8.1	9.7	9.9	6.9	11.0	10.9	9.8	13.4	14.0	12.6	8.9	9.1	6.5	15.3	17.5	16.1
South Wales	13.9	14.4	7.4	9.4	7.7	3.2	10.4	10.7	5.6	11.0	11.5	8.5	15.4	16.1	11.6	9.5	9.4	4.2	15.3	18.9	17.9

Statistics on outdoor fires in England and Wales were used by Defra as one of the UK Climate Change Indicators (indicator 16)⁴⁵. Analysis used a comparison between fire data for 1984-2001 and mean rainfall, June to August (Figure A3.6). For the complete series, the correlation between the number of outdoor fires and England and Wales summer rainfall was -0.74. Further analysis has used more recent data held by the Department for Communities and Local Government (DCLG). This shows a strong correlation between the frequency of fire and the 'heat wave' years of 1995, 2003 (shown as the red ellipses in Figure A3.7).

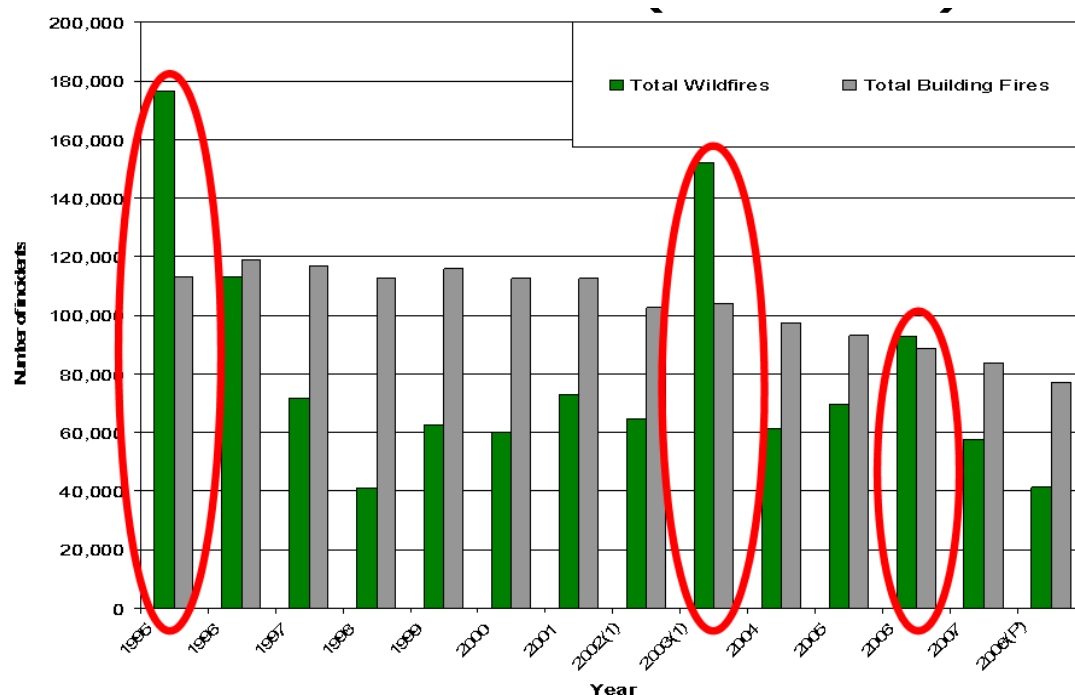
Since 2009, fire reporting in the UK has used the Incident Reporting System (IRS) (Gazzard, 2009). Additional information collected under the IRS includes the location of the fire, the extent of the fire and whether the fire was in a national park (DCLG, 2009).



Source: Environmental Change Network (<http://www.ecn.ac.uk/iccuk/indicators/16.htm>) NB – Original source incorrectly labelled the y-axis on the lower graph, units unknown.

Figure A3.6. Relationship between outdoor fires and summer precipitation

⁴⁵ <http://www.ecn.ac.uk/iccuk/indicators/16.htm>



Source: Gazzard R, 2010, 'Development of wildfire statistics and risk impacts in the United Kingdom', Fire and Rescue Statistics User Group (FRSUG). <http://www.frsug.org/reports/>

Figure A3.7. Outdoor fires in the UK (1995 – 2008) and heat wave years

Potential impact of climate change

A range of established fire danger indices exist, including the McArthur Forest Fire Danger Index (FFDI), the Canadian Forest Fire Weather Index (FWI) and the US National Fire Danger Ratings System (NFDRS) (Dowdy *et al.*, 2009). The Met Office has recently undertaken preliminary modelling of climate change effects on fire danger using the FFDI, as previous experience indicated that it correlated well with actual fire events in the UK (Meteorological Office, 2005). The FFDI combines the probability of a fire starting, rate of spread, intensity, and difficulty of suppression into a single index derived from the following variables:

- daily maximum temperature
- daily minimum relative humidity
- daily mean wind speed
- number of days since last rain
- total rain in the most recent 24 hour period with rain
- soil moisture content.

Development by the Met Office of the FFDI for climate change is based upon work carried out in the Amazon basin (Golding and Betts, 2008). This has been updated for the UK through use of the 11-member Regional Climate Model (HadRM3) ensemble associated with UKCP09. Within the FFDI scale, a value of 1 means fire will not burn while 5 to 12 is a 'moderate risk'. The system is an Australian one and so values for the UK are lower in the overall scale. The results of this analysis (Figure 5.4) need to be interpreted with caution as they provide only change in annual mean values; it would be assumed that likely values would be higher in the summer months. In addition, only one climate model has been used, although the various HadRM3 ensemble members consistently show an increase in the FFDI for the 2080s, especially in the south of the

UK. Finally, the coarse resolution of the soils and land cover data used in the modelling mean that the fuel (biomass) component that is the key element in wildfire risk is probably poorly represented. Any event also requires a trigger: although there are natural causes of wildfire in the UK (e.g. lightning), these are extremely rare, with events being predominantly caused by the actions of people (either accidentally or deliberately).

To provide an indication of how these national-scale results may affect land managers at the local scale, model results (% difference) have been extracted for national parks across England, Scotland and Wales (Table 5.3), highlighting the higher risk rating for all areas in the future with the largest changes in the south.

The figures presented are from preliminary analysis of climate model projections and relate to annual average change only, meaning that they give no indication of the possible impact of changing inter-annual variability or extreme events such as heat waves. As shown in Figure A3.7, the number of outdoor fires increases during such events, although it is not clear how much this increase is related to a change of wildfire risk or the increased opportunity for ignition (for example though increased visitor numbers or barbecues in vulnerable locations). More detailed regional analysis of the wildfire risk in the Peak District by Albertson *et al.* (2010) suggested little change in the short term but potentially major changes in fire regime in the medium to long term. An important interaction with the changing seasonal phenology of vegetation growth and decay was noted which might lead to significant changes in the length and intensity of the 'at risk' season.

Of particular significance is the damage that fire can cause to areas of peat - such habitats are a significant carbon sink. Once ignited, peat habitats can burn and 'smoulder' for an extended period and are difficult to extinguish. Where there is damage as a result of fire, carbon stored within the peat can be released back to the atmosphere and the ability of the habitat to act as an effective carbon sink is severely constrained. It is also possible that the original vegetation communities, such as blanket bog or wet heath, cannot be re-established.

Conclusions

The climatic conditions that would promote an increase in wildfire risk such as higher temperatures, lower summer rainfall and drier soils are projected to increase. This may result in large changes in habitat and species populations, with frequent fires associated with open habitats (grassland and heath). There may also be damage to peat and consequent release of carbon into the atmosphere. Wildfires can have a number of socioeconomic effects, including the obvious risk to human health and the impacts on forestry, agriculture, and the built environment. As most fires are caused by human agency, either accidental or by deliberate action, there is also the prospect of increased use of closure orders to restrict access to high risk areas (e.g. heath and moor) that are important for a range of ecosystem services (e.g. water resources, carbon storage). This would have implications for access and recreation.

Appendix 4 Magnitude, Confidence and Presentation of Results

Table A4.1 defines the magnitude classes used in the assessment. These were used for scoring impacts in the Tier 2 selection process as well as for scoring risk levels for the scorecards presented for each metric in Chapter 5. For the scorecard, the risk/opportunity level relates to the most relevant of the economic/environmental/social criteria.

Table A4.1 Guidance on classification of relative magnitude: qualitative descriptions of high, medium and low classes

Class	Economic	Environmental	Social
High	<ul style="list-style-type: none"> Major and recurrent damage to property and infrastructure Major consequence on regional and national economy Major cross-sector consequences Major disruption or loss of national or international transport links Major loss/gain of employment opportunities <p><i>~ £100 million for a single event or per year</i></p>	<ul style="list-style-type: none"> Major loss or decline in long-term quality of valued species/habitat/landscape Major or long-term decline in status/condition of sites of international/national significance Widespread Failure of ecosystem function or services Widespread decline in land/water/air quality Major cross-sector consequences <p><i>~ 5000 ha lost/gained</i> <i>~ 10000 km river water quality affected</i></p>	<ul style="list-style-type: none"> Potential for many fatalities or serious harm Loss or major disruption to utilities (water/gas/electricity) Major consequences on vulnerable groups Increase in national health burden Large reduction in community services Major damage or loss of cultural assets/high symbolic value Major role for emergency services Major impacts on personal security e.g. increased crime <p><i>~million affected</i> <i>~1000's harmed</i> <i>~100 fatalities</i></p>
Medium	<ul style="list-style-type: none"> Widespread damage to property and infrastructure Influence on regional economy Consequences on operations & service provision initiating contingency plans Minor disruption of national transport links Moderate cross-sector consequences Moderate loss/gain of employment opportunities <p><i>~ £10 million per event or year</i></p>	<ul style="list-style-type: none"> Important/medium-term consequences on species/habitat/landscape Medium-term or moderate loss of quality/status of sites of national importance Regional decline in land/water/air quality Medium-term or Regional loss/decline in ecosystem services Moderate cross-sector consequences <p><i>~ 500 ha lost/gained</i> <i>~ 1000 km river water quality affected</i></p>	<ul style="list-style-type: none"> Significant numbers affected Minor disruption to utilities (water/gas/electricity) Increased inequality, e.g. through rising costs of service provision Consequence on health burden Moderate reduction in community services Moderate increased role for emergency services Minor impacts on personal security <p><i>~thousands affected, ~100s harmed, ~10 fatalities</i></p>
Low	<ul style="list-style-type: none"> Minor or very local consequences No consequence on national or regional economy Localised disruption of transport <p><i>~ £1 million per event or year</i></p>	<ul style="list-style-type: none"> Short-term/reversible effects on species/habitat/landscape or ecosystem services Localised decline in land/water/air quality Short-term loss/minor decline in quality/status of designated sites <p><i>~ 50 ha of valued habitats damaged/improved</i> <i>~ 100 km river quality affected</i></p>	<ul style="list-style-type: none"> Small numbers affected Small reduction in community services Within 'coping range' <p><i>~1000's affected</i></p>

The levels of confidence used by the CCRA can be broadly summarised as follows:

Low - Expert view based on limited information, e.g. anecdotal evidence.

Medium - Estimation of potential impacts or consequences, grounded in theory, using accepted methods and with some agreement across the sector.

High - Reliable analysis and methods, with a strong theoretical basis, subject to peer review and accepted within a sector as 'fit for purpose'.

The lower, central and upper estimates provided in the scorecards relate to the range of the estimated risk or opportunity level. For risk metrics that have been quantified with UKCP09 and response functions, this range relates to the results that are given for the low emissions, 10% probability level (lower); medium emissions, 50% probability level (central); and high emissions, 90% probability level (upper). For the risk metrics that have been estimated with a more qualitative approach, these estimates cover the range of potential outcomes given the evidence provided.

The CCRA analysis uses three discrete time periods to estimate future risks up to the year 2100: the 2020s (2010 to 2039), 2050s (2040 to 2069) and the 2080s (2070 to 2099). This is consistent with the UKCP09 projections.

