UK Forestry Standard **Practice Guide**

Adapting forest and woodland management to the changing climate

Forestry Commission

Scottish Forestry
Coilltearachd na h-Alba

Cyfoeth Naturiol Cymru
Natural Resources Wales

FOREST SERVICE

Adapting forest and woodland management to the changing climate

UK Forestry Standard Practice Guide

Forestry Commission
Scottish Forestry
Coilltearachd na h-Alba
Cyfoeth Naturiol Cymru
Natural Resources Wales
Forest Service

This publication is also available on our website at: www.forestresearch.gov.uk/publications

First published by the Forestry Publishing Group in 2022.

ISBN: 978-1-83915-016-6

Keywords: adaptation; climate change; forests, planning; UK Forestry Standard; woodland creation; woodland management.

Enquiries relating to this publication should be addressed to:

Forest Research
Silvan House
231 Corstorphine Road
Edinburgh EH12 7AT
0300 067 5000
publications@forestresearch.gov.uk

Technical author contact:

Dr Gail Atkinson
Forest Research
Alice Holt Lodge
Farnham GU10 4LH
0300 067 5600
gail.atkinson@forestresearch.gov.uk

Technical editors: Dr Gail Atkinson, Dr James Morison and Dr Bruce Nicoll, Forest Research.

The editors would like to thank colleagues, forestry sector practitioners and landowners from across the UK for their helpful input to this Practice Guide.

Forest Research

Forest Research is Great Britain's principal organisation for forestry and tree-related research and is internationally renowned for the provision of evidence and scientific services in support of sustainable forestry. The work of Forest Research informs the development and delivery of UK Government and devolved administration policies for sustainable management and protection of trees, woods and forests. For more information visit: www.forestresearch.gov.uk

Forest Research will consider all requests to make the content of its publications available in alternative formats. Please send any such requests to publications@forestresearch.gov.uk.

Contents

Introduction

Our climate is changing rapidly. Milder, wetter winters, warmer, drier summers and longer growing seasons are expected, together with more frequent extreme climate events such as extended periods of heavy rainfall, heatwaves and drought. The projected rate of climate change we face is unprecedented. There is a widely acknowledged climate emergency and assessing how we manage our forests and woodlands so that they can adapt to these changes is essential. It is in the interests of both forest and woodland owners and wider society, given the essential roles that trees and woodlands play in our landscapes (Figure 1).

Climate projections show that summer temperatures could be between 1 and 5°C warmer by 2070 than in the period 1981–2000, and the probability of summers as hot as 2018 increases from <10% to approximately 50%.

Woodlands, forests and forestry have a substantial role in helping to reduce climate change. Trees remove carbon dioxide from the atmosphere and store the carbon in solid form as wood. The harvesting and use of wood from sustainably managed forests transfers the carbon into wood products where it can continue to be stored, often over long periods, in materials such as those used for construction and furniture. Wood products can also be used as an alternative to other materials that release greenhouse gases in their production, such as concrete and plastics, and woody biomass can be used directly as a source of energy to replace fossil fuels. Mitigation and adaptation therefore need to be considered together to ensure that adaptation actions do not solve one problem while creating another. Forests and woodlands should provide multiple benefits, while retaining flexible management options for the future.

The United Kingdom Forestry Standard (UKFS) advocates the development of a risk-based approach to adaptation that minimises the potential for negative impacts on tree growth and forest productivity using adaptation measures. Even if there are strenuous global efforts to reduce greenhouse gas emissions, the UK's climate will continue to change. These changes and the risks they present could be large although there is uncertainty. Therefore, woodland owners and managers should assess the risks that climate change poses, and plan adaptation accordingly.

Figure 1 How we manage our forests and woodlands so they can adapt to change is essential to maximise the range of benefits that trees provide to society and the environment.

Aim and scope

This Practice Guide provides information on how to better understand and assess the risks associated with climate change, in order to plan for the future and adapt forest and woodland management. Our knowledge of the likely effects of climate change is continually improving and this Guide brings together recent insights from research and forestry practice. The Guide presents an adaptation framework that can be applied to forest and woodland management in many situations to help managers consider the likely impact of future climate scenarios, to decide whether action is required, and to guide the selection and implementation of appropriate adaptation measures to address climate risks and opportunities. The Guide is primarily for forest and woodland owners and managers, planners, advisors and policymakers.

The focus of this Guide is on climate change adaptation, recognising that this is an essential component of improving the overall resilience of forests and woodlands and a requirement of the UKFS. The Guide is not intended to be prescriptive and cannot cover all possible changes and adaptation measures; those measures will have to be chosen by managers to suit sites, locations and objectives. Furthermore, a diverse array of approaches is likely to be beneficial.

The Guide does not cover the important role that existing UK forests and woodlands play in tackling climate change by reducing net greenhouse gas emissions, nor does it explore the potential for increasing carbon uptake and sequestration through woodland creation. However, it is important to keep in mind that these climate change mitigation roles will be enhanced if trees, woods and forests are made more resilient by adaptation.

The Guide builds on the information provided by the UKFS, and works alongside information and advice at country level (see Further reading and useful sources of information and Appendix 1). Adaptation within the forestry sector is a component of the wider national adaptation planning across all sectors in the UK's devolved administrations.

The Guide is supported by a series of case studies of forests and woodland that are being adapted for climate change in order to demonstrate 'adaptation practice'. These are examples of what owners and managers are doing to respond to climate change in their woodlands and to prepare for future changes. The case studies and further detailed information on available resources and support can be found in Appendix 2 at the end of this Guide and at forestresearch.gov.uk/adapting-forest-management-to-the-changing-climate.

Planning for adaptation

The changing climate presents substantial challenges for managers of forests and woodlands because past approaches to land management are unlikely to lead to the same outcomes in the future. Significant changes are likely to be needed now to what have previously been accepted practices in order to ensure that woodlands continue to provide the multiple benefits they currently do. Climate change also provides potential opportunities; for example, faster tree growth in some locations. Those involved in decision-making should take these changes into account in management plans to best prepare woodland and forests for future conditions.

The UKFS includes good forestry practice requirements relevant to climate change, including those for adaptation and protection. It requires forests to be planned and managed to enhance their resilience and mitigate the risks posed to their sustainability by the effects of climate change or attack by pests and disease.

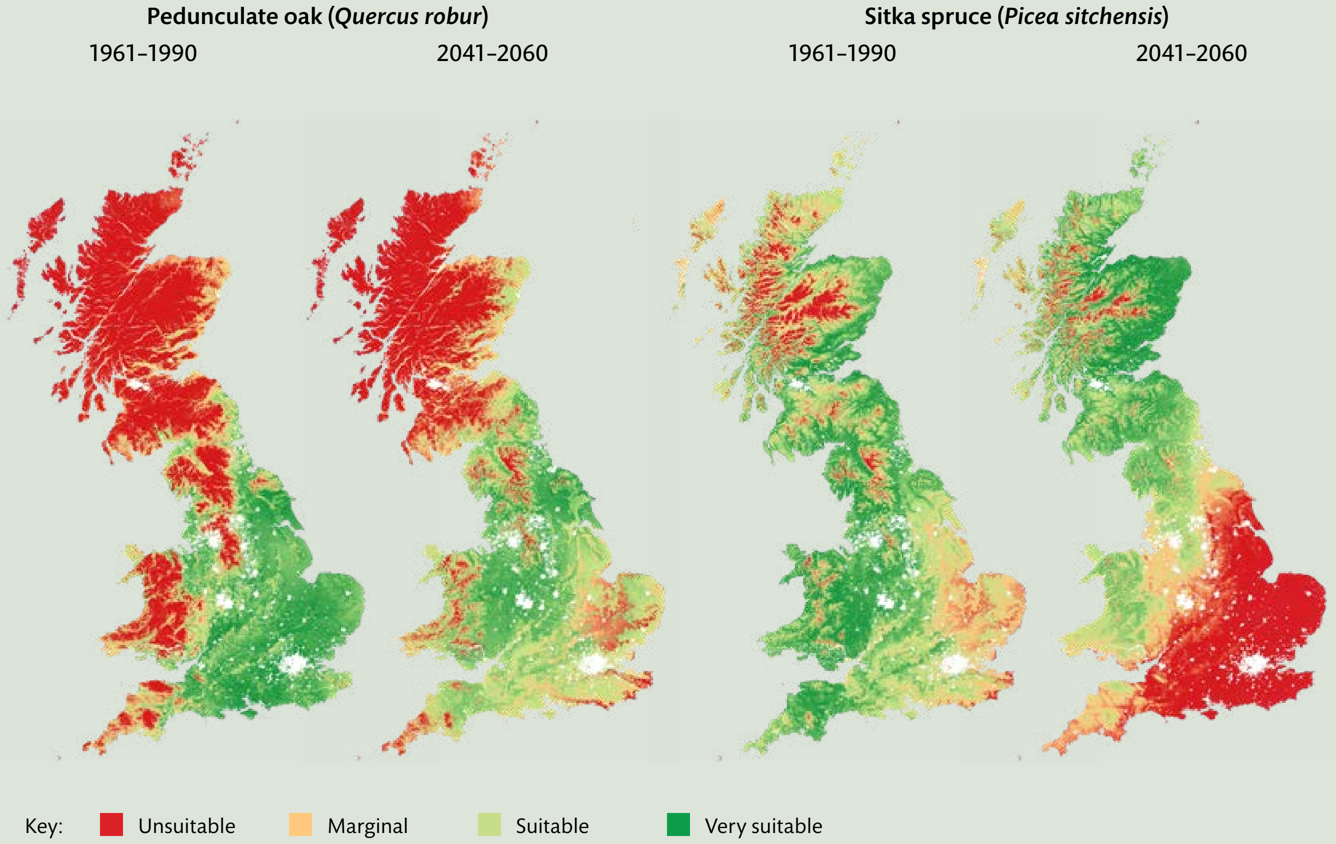
Furthermore, the Standard requires forest management to enhance the potential of forests to protect society and the environment from the various effects of climate change.

While the latter is a critical element of adaptation, and should also be given due consideration, this Guide focuses on the first of these requirements: explaining how forests can be managed to enhance resilience and mitigate risks from the effects of climate change.

The impacts of the changing climate on a tree species vary spatially according to site and landscape characteristics. The land use, topography and other non-climatic features of the surrounding landscape will also dictate how well suited a species is to the changing climate. Box 1 shows an example of a national scale suitability assessment for two tree species – pedunculate oak and Sitka spruce – using the Forest Research Ecological Site Classification (ESC) tool (see page 41) and Met Office projections of climate change.

Box 1 Species suitability assessment for pedunculate oak and Sitka spruce

The maps below show how the suitability of two tree species could change in different parts of Great Britain* by around 2050, compared with that in the climate that occurred in the period 1961–1990. Using this particular projected climate change from UKCP09 (which assumes a medium-high global greenhouse gas emissions scenario), the suitability for pedunculate oak is expected to decline in southeast England, particularly across East Anglia, while it is expected to improve near the east coast of Scotland. For Sitka spruce, a species that is better suited to cooler, moist conditions, it is projected to become less suitable in warmer, drier regions, but with suitability increasing in cooler, upland areas. It is important to realise that these are not predictions but depend upon the scenarios used; and that such large-scale analyses do not necessarily indicate what might happen at particular sites, with local soil, topography and microclimate conditions, nor do they account for pest and disease risk.



*The Forest Research Ecological Site Classification tool does not currently cover Northern Ireland.

Adaptation framework

This Guide presents an Adaptation framework for managing forests and woodlands for the changing climate. The starting point is the management plan for the area. It is a UKFS requirement to have a forest management plan, and preparing a plan provides many benefits. Preparation will involve reviewing the main management objectives for the area, under the overarching objective of sustainable forest management (as defined in the UKFS) and considering the changing climate. Management objectives will differ between woodlands and areas within the woodland and different components are often complementary. Advice and tools to assist with management planning and the plans required for applying for grants are available from the forestry authorities (see Further reading and useful sources of information on page 43).

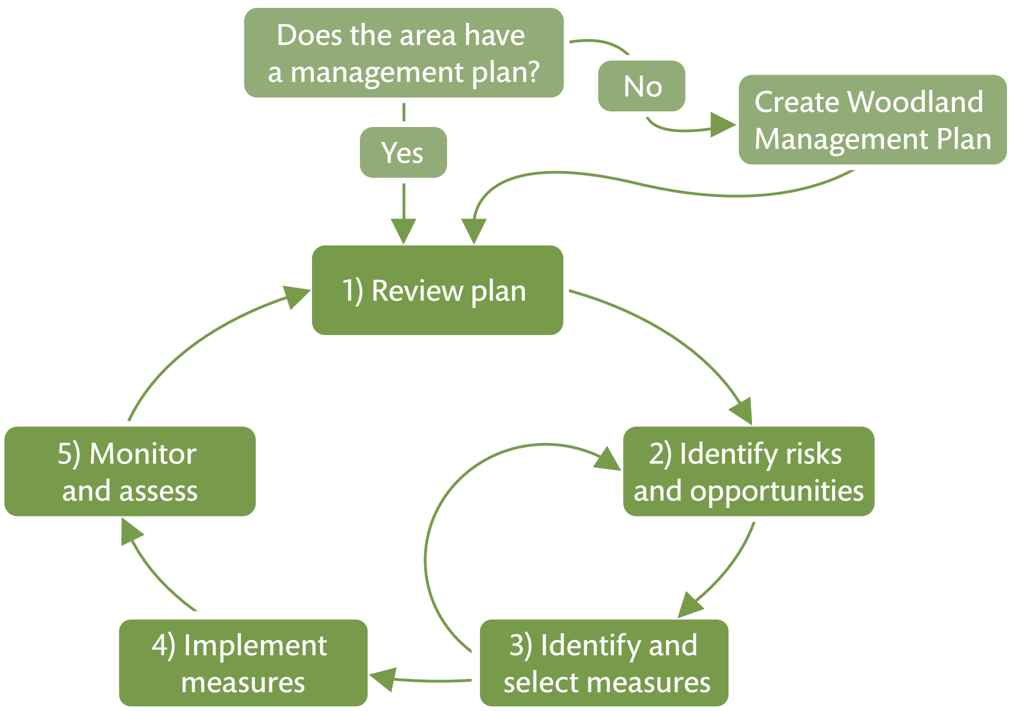
The Adaptation framework has five distinct steps or stages, which are illustrated in Figure 2.

- Step 1 is to review the management plan and check whether and to what extent the changing climate has been considered in the plan.

- Step 2 is to identify risks and opportunities from climate change factors in the area. Assessing the vulnerability of the area to present and future risks will involve a review of the main risks and whether they are acceptable or not. This requires consideration of both average changes in climate over time and likely changes in the frequency and severity of extreme events, before deciding if action is necessary.

- Step 3 is to identify and select adaptation measures, if action is required. This requires careful consideration of measures that could minimise the risk of decreasing yields, tree mortality, habitat loss, or increase the multiple benefits of woodland as they change over time.

Figure 2 The five-step Adaptation framework.



• **Step 4** is to implement the measures at the appropriate time.

• **Step 5** is monitoring and assessment, which completes one cycle of the Adaptation framework and should then lead back to a review and reassessment of the necessary actions.

The circular, iterative process in the five-step Adaptation framework is necessary, not least because climate change is continuous – not simply a single-step change in conditions – so adaptation opportunities and requirements need to be reassessed over time. Furthermore, it is not always clear what the results of any changes in management will be, given the complexities and changing climatic, ecosystem and socioeconomic conditions. It is necessary to continue to review, and potentially revise, adaptation decisions in the light of accumulating knowledge and changing climatic conditions. Each step of the Adaptation framework is discussed in detail in the following sections.

> **!**
> Monitoring the effectiveness of applied measures is essential to provide valuable information to inform future adaptation plans and activities. The monitoring should be long-term as there may be long lags between applying measures and observing the effects.

The Adaptation framework in practice

The Adaptation framework has been applied to a range of case studies, which are available as supporting resources at forestresearch.gov.uk/adapting-forest-management-to-the-changing-climate. One of the case studies, the adaptation of a stand in Alice Holt Forest (Figure 3), is also provided here in flowchart format, as an example to illustrate the application of the framework (Figure 4). In the case of Alice Holt Forest, this involved assessing the main climate risks to 2080, identifying adaptation measures, and implementing the selected measures. The greatest risks were identified as drought and vulnerability to pests and pathogens. Several adaptation measures were incorporated into the management prescription to reduce these risks. For example, management has changed from clearfell to the use of an alternative cover system, meaning that some canopy cover is being retained to protect new planting from temperature extremes and drought. Species expected to decline in terms of suitability to future conditions, particularly beech, were not excluded entirely from planting, but they now account for a lower percentage of the overall species mix in preference for species with a greater drought tolerance, especially hornbeam.

Figure 3 Alice Holt Forest in southeast England is a large research forest with multiple management objectives. A selection of adaptation measures were implemented in parts of the forest during management operations in the winter of 2017–2018.

Courtesy of Forestry England

Figure 4 Illustration showing the application of the adaptation framework to a stand in Alice Holt Forest in Hampshire.

Site description – Holt Pound, Alice Holt Forest: A stand of Corsican pine (*Pinus nigra*) planted in 1940 on an ancient woodland site with sandy soil. Alice Holt is an important, large research forest with high visitor numbers, situated in southeast England. There are multiple objectives for the forest and the individual stands within it.

Application of adaptation framework at Alice Holt	Analysis and possible measures	Recommendations
1. Review plan Review Holt Pound forest management plan objectives	**Management planning** – multiple objectives for the stand including: timber production; PAWS[1] restoration; biodiversity; recreation. Adaptation to climate change was added as a management objective in the Forest Management Plan in 2016.	
2. Identify risks and opportunities (i) Climate change risks	• **CO_2** – is predicted to be between 430 and 760 ppm by 2080. • **Temperature** – by 2080 summer mean temperature is expected to increase by up to 4.2°C. - Current stand established and tree species is expected to tolerate increasing temperature. - Future stands must tolerate increasing temperature. - Longer growing season may benefit production[2]. • **Rainfall** – likely to be lower summer rainfall.	Ensure future woodland can tolerate: • Increasing temperature. • Lower summer rainfall on sandy soils. • Potential drought stress. • Other variables, such as a reduced frequency of air frosts and snow days.
(ii) Stand vulnerabilities	• **Impact of hotter, drier summers**. • **Impact of increasing temperature** on trees that have regenerated from seed or have been newly planted, in tandem with reduced soil moisture availability for the current stand. • **Likelihood of drought** occurring, projected increase between 10 and 50%. • **Heat stress**, which is likely to increase tree damage from pest and disease attacks. • **More frequent extreme weather events**, e.g. severe windstorms and droughts could lead to a significant impact on tree growth, biodiversity and other benefits.	Choose species tolerant to increasing temperatures and drought stress on sandy soil. If retaining any of the current stand, account for the water demand of Corsican pine (higher than some other pines). • Choose wind-stable species due to ridge topography. • Avoid species vulnerable to pest/disease outbreaks.
3. Identify and select measures Potential adaptation measures at Alice Holt	• **Species and genetic diversity** – increase tree species diversity. Choose broadleaved species to produce quality timber, meet PAWS[1] restoration objectives and select more drought-tolerant types, favouring more wind-stable species. • **Structural diversity** – widen age structure by transition to alternative cover systems. • **Managerial adaptation** – increase deer/squirrel management to prevent browsing damage and to promote regeneration. • **Contingency planning** – for wind, drought and wildfire events.	Review tree species suitability for future planting at this site to the end of the century (from the 61 different species identified in the ESC[3] under a medium/high 2080 emission scenario). Further assess results for secondary risks, e.g. susceptibility to pests/disease.
4. Implement measures Management prescription	• **Underplant** with two different broadleaved species (beech and hornbeam) to meet restoration objectives, increase species diversity, widen the age range, demonstrate drought tolerance and increase the use of native broadleaved species. Hornbeam is expected to perform better than beech in future because it has a higher drought tolerance. • **Test adaptation measures** and monitor forest response. • **Undertake contingency planning** for wildfire across a wider area.	• Lightly thin current stand of Corsican pine to increase light and clear understorey. • Mulch to clear regeneration/scrub and prepare for planting. • Fence and split area into two sub-compartments. • Underplant in an intimate mixture with hornbeam and beech of UK405 provenance. • Adjust the balance of the two tree species in area A to include more hornbeam.
5. Monitor and assess	**Monitoring and assessment** to include (i) a list of measures considered and rationale for implementation and (ii) details of implementation (e.g. cost, planting date, tree supplier, species). **Annual assessment** for the first five years of: pre-operation tariff data; beat-up rate; growth (height and diameter at breast height); and observations (e.g. mammal damage, disease symptoms).	

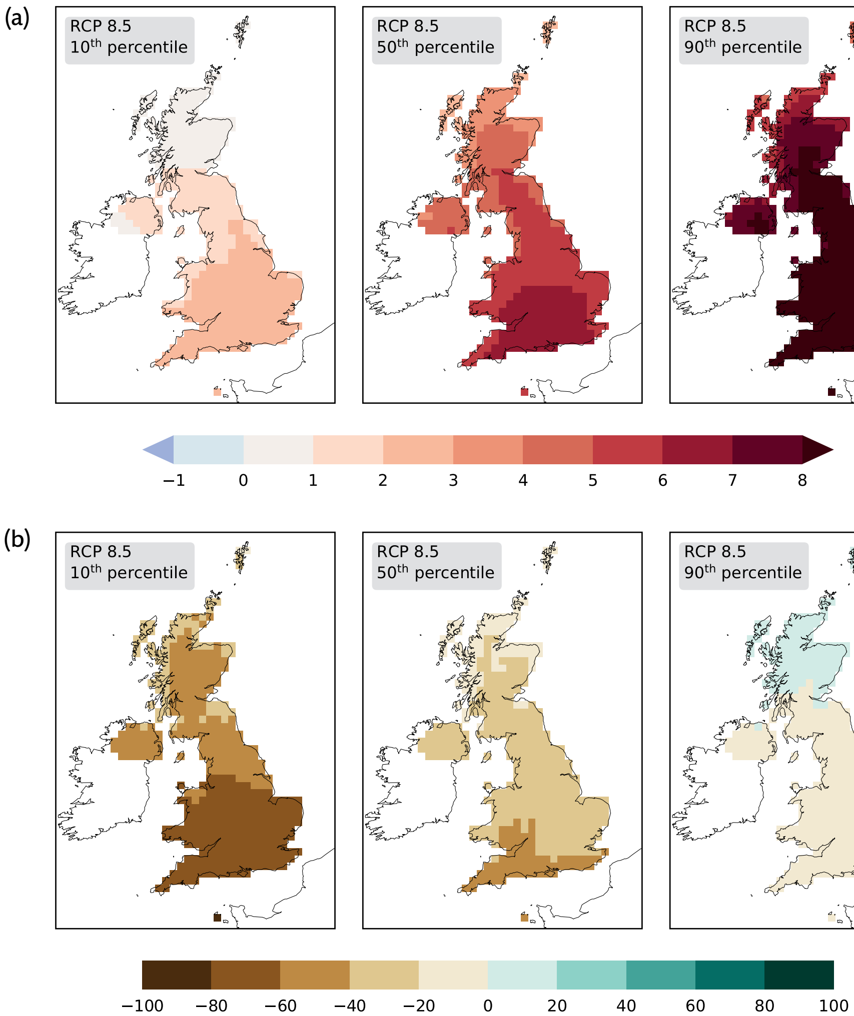
[1]Plantations on Ancient Woodland Sites. [2]Where other factors are non-limiting. [3]Forest Research Ecological Site Classification

Identifying climate change risks and opportunities

Rapid changes in our climate are being driven by recent and continuing human influences on the atmosphere and the land surface. These changes are resulting in an increase in global surface temperatures, and consequent changes in regional weather patterns, alongside increases in sea levels. Our understanding of the global emissions of greenhouse gases, changes in land use, and the various feedbacks in the land–climate–ocean system are used in models to make projections of likely future climate conditions for different regions. The climate trends and projections can then be compared with a baseline climate (i.e. the climate we were used to, such as during the period from 1981 to 2000 used in the example maps in Figure 5) in order to assess impacts, risks and opportunities. It is important to recognise that much of our woodland management practice was developed in a previous period with a measurably different climate and may not be fit for a rapidly changing climate.

The UK Climate Projections (UKCP) produced by the UK Met Office is an essential tool to show the likely future climate in different parts of the UK. The latest projections (UKCP18) show an increased chance of milder, wetter winters and hotter, drier summers and an increase in the frequency and intensity of extreme events. The maps in Figure 5 show the large-scale patterns of projected changes across the UK to the end of the century, with climate characterised by two key measures for tree growth: summer mean maximum air temperature and summer rainfall.

Figure 5 Maps of projected change in (a) 20-year mean summer (June, July and August) maximum temperature (°C) and (b) precipitation (% change – negative values indicate reduced rainfall) in 2080–2099, compared with 1981–2000.



The maps in the middle of the top and bottom rows show the 50th percentile values, the middle of the range of projections. The left-hand maps show the 10th percentiles, that is the low end of the range of projections (only 10% of projections being lower). The right-hand maps show the high end of the range (only 10% of projections being higher). Therefore, for example, the middle of the likely range for the increase in mean summer maximum temperature in the Scottish Borders at the end of the century is 3–4°C, but there is a wide range, with 80% of the projections lying between 1 and 8°C.

Figures produced for the high global emissions scenario (Representative Concentration Pathway (RCP) 8.5) courtesy of the Met Office Hadley Centre.

These maps have been produced assuming that global emissions will remain high and result in a global temperature increase of 4°C by the end of the century. This is not extreme; the UK Committee on Climate Change has noted that current global plans for emissions reductions give only a 50% chance of meeting a 3°C maximum global temperature rise. They advise that 'planning for a minimum of 2°C, with consideration of more extreme scenarios should be a requirement' (see the Committee on Climate Change's 2020 progress report to Parliament on *Reducing UK emissions* for further information).

The full series of Climate Change Impacts Report Cards (published by LWEC), which present evidence on how climate change affects different aspects of our environment, economy and society, are available from nerc.ukri.org/research/partnerships/ride/lwec/report-cards

Changes in climate that have occurred recently in the UK are described in the Met Office annual reports. The impacts of climate change on woodland vary depending on the location and site characteristics. Different components of our woodlands are being affected differently, which can alter inter-relationships and the timing of plant and animal lifecycles. The changing climate can also affect woodlands and forests indirectly; for example, by changing the demand for land for crops, grazing or flood protection, or by altering global timber production and markets. These impacts are considered in more detail in the Climate Change Impacts Report Cards on *Agriculture and Forestry* and *Biodiversity*. Risks for the natural environment have been reviewed in Chapter 3 of the Technical Report of the Third UK Climate Change Risk Assessment at www.ukclimaterisk.org/independent-assessment-ccra3/technical-report.

The main climate factors subject to change include carbon dioxide (CO_2) concentrations, temperature, rainfall, wind, storms, sea level, flooding and frost and snow events. Table 1 lists the likely future changes in the UK climate and possible impacts on forests, woodland and trees. It is important to understand the climate changes expected in an area to identify and plan for the risks and opportunities they will bring. We provide generalisations of the changes ahead and provide links to tools that offer more detailed projections of changes expected in different parts of the country, such as the Met Office reports and climate change maps at www.metoffice.gov.uk/research/approach/collaboration/ukcp.

Assessing climate change risks and opportunities

Managing forests and woodlands will usually involve assessing (either explicitly or implicitly) exposure to risks that could damage the trees or alter their growth or productivity, affect any revenue, or prevent the owner or manager from achieving desired objectives. The UKFS provides recommendations and guidelines about good forestry practice that will help reduce presently familiar risks, such as best practice in pest and disease management. The key point now is that the changing climate means that there will be new and unfamiliar risks, caused by new climate conditions or new combinations of weather, or that the exposure to existing risks may have altered or will alter in the future. The manager needs to assess these risks in order to identify possible adaptation measures and Table 1 offers an overview. There may also be opportunities from the changing climate: longer growing seasons may increase tree growth rates, while warmer conditions and fewer, less severe frosts may allow a wider range of species. The same tools that enable risk assessment can often be used to assess opportunities, for example on species choice (see Increasing species diversity on page 20). In this section, key risks are examined in more detail, but it is essential to assess these risks depending on the site, and then reassess them over time as the climate continues to change. The next section describes some of the adaptive measures that could be appropriate.

Windthrow risk

Wind is a major threat to woodlands and forests, particularly in upland and exposed areas.

Table 1 The main likely future changes in the UK climate to the end of the century, possible risks and opportunities for forests and woodland and site factors that are likely to increase the risk or opportunity from them.

		Risk/opportunity	Influencing site factors
Carbon dioxide increase	Atmospheric CO_2 concentration will continue to increase, depending on global measures to reduce emissions. By 2050, CO_2 concentration could be between 440 and 540 ppm, compared with the pre-industrial 280 ppm.	Increased tree growth (also, increased growth of other vegetation)	Increases may be constrained by changes in rainfall, soil water availability, nutrition, pests and disease and other limiting factors. Warmer temperatures may be more beneficial in cooler, wetter upland areas than in drier, warmer lowland areas.
Temperature increase	All UK regions are expected to warm – more in summer than in winter. The growing season will become longer. Warmer temperatures imply reductions in humidity, particularly in summer, and could cause drought. Changes in phenology.	New species options Nursery production planning Pests and disease	Risks increased by: • Monocultures or low levels of species, genetic or structural diversity • Sites with poor biosecurity • Sites where trees are stressed by other pressures such as wind or drought • Undermanaged/unmanaged sites • New tree species with higher vulnerability than existing species.
Rainfall change	Reduced rainfall: There may be lower summer rainfall, particularly in southern and central England. In conjunction with warmer average temperatures, this will increase the risk of droughts, both duration and frequency. Lower summer rainfall implies increased solar radiation.	Wildfire	Risks are higher for: • Young stands of pine, spruce, fir, cypress or eucalyptus • Newly established plantings where there is substantial ground vegetation • Little silvicultural diversification • High recreational use, particularly during hot, dry periods • Undermanaged or unmanaged sites • Limited or no fire risk-reduction measures • High fire risk in adjacent areas, e.g. moorland • Outbreaks of pests/disease that increase available fuel • Located in drier locations, e.g. southern England.
		Drought	Risks are higher for: • Young and newly planted trees • Light/shallow soils that hold less water than deep soils • Woodland on brownfield/restored landfill • Tree species and species combinations with poor drought tolerance • High ground vegetation competition • Lack of mixed planting, as some species can 'lift' water from deeper soils • Sites located in southern or central England.
	Increased rainfall: summer rainstorms may be heavier when they do occur. Together with the trend towards higher winter rainfall, this suggests that wetter soils and flooding are more likely.	Flooding and waterlogging	Risks are higher for sites with: • Poorly drained, heavy soils • Limited or poorly maintained road networks • Flooding during the growing season is more damaging to trees • Lowland and floodplain forests and woodlands • Species sensitive to root damage during waterlogging • Proximity to coast and possible saltwater flooding.
Sea level rise	Sea level will continue to rise, probably at a faster rate than previously observed, and lead to higher peak sea levels during storms; higher risk of sea water intrusion.		
Reduced frost and snow days	The number and severity of air frosts are expected to decline; however, their timing in relation to plant and animal cycles may change. Significant reductions in the number of snow days, mean snowfall rates and the frequency of heavy snowfall events are projected.	Frost damage Pests and disease	• Frost-prone sites and/or tree species vulnerable to frost damage • Species with short dormancy or dormancy changing as a result of climate change • New woodland creation sites/new planting • Increase of pest or disease populations previously constrained by cold temperatures.
Increased storm frequency and wind speeds	Changes to atmospheric circulation may lead to a shift in storm tracks. Some increase in winter storms and average wind speed is expected.	Windthrow	• High elevation and exposed sites • Tree species vulnerable to wind • Gleyed shallow soils • Recent harvesting activity nearby • Recent stand thinning • Undermanaged or over-mature stands • Increased volume of damaged timber.

For production forestry, storm damage can lead to increased costs of harvesting and reduced timber value. Increased volume of storm-damaged timber can also increase pest and disease occurrence. There are also indirect costs, such as loss of amenity value and public access, safety concerns for forest workers and visitors and damage to important wildlife habitat, as occurred in the notable storms of recent decades (e.g. 1987, 1990, 1998, 2005, 2012, 2021 and 2022). Wind risk is influenced by exposure of the site, tree species, soil type and stand spacing, and increases as trees grow in height. The risk of wind damage might increase as the climate changes as a result of more frequent storms, faster tree growth, longer period in leaf for deciduous species or reduced root anchorage as a result of increased waterlogging. The UKCP18 projections indicate that there is likely to be an increase in the frequency of winter storms and a modest increase in wind speeds in winter in the latter half of this century.

ForestGALES can be used to assess the risk of wind damage to forest stands in relation to management options. See forestresearch.gov.uk/forestgales

ForestGALES, Forest Research's wind risk decision-support tool can be used to evaluate the wind risk for a site or a forest area, so that it can be effectively managed. ForestGALES can calculate wind risk based on current stand characteristics, or it can show how risk will change over time as the stand grows. It can be used to explore the changes to wind risk that result from management actions, such as stand thinning or harvesting of neighbouring stands.

The Case study on changing wind risk in Queen Elizabeth Forest Park in Scotland was developed using ForestGALES (see forestresearch.gov.uk/adapting-forest-management-to-the-changing-climate). Management decisions in the forest park reflect the wind climate and risk of damage in relation to operations including thinning, conversion to continuous cover forestry and the timing of harvesting.

Wildfire risk

Wildfires can start within forests or spread in from adjacent areas, such as grassland, heathland or moorland (Figure 6). Presently there are two main fire-risk periods: spring, when there is dried-off, dead ground vegetation present (e.g. grass, bracken), and summer, when hot and dry spells occur. The latter are usually more damaging. The changing climate is likely to increase the risk of wildfires in both periods, and these particular risk periods may be altered or extended. Warmer, drier weather conditions and more frequent and longer dry

Figure 6 It may not be possible to prevent wildfires, such as this one at Swinley Forest in Berkshire, completely, but wildfire resilience can be improved through good forest management planning.

spells increase the risk of fires starting, and risks of spread may also be increased if there is more ground vegetation growth, or more litter fuels because of pest or disease outbreaks. Wildfires can have many substantial impacts. The impact can be economic, for example, through the loss of tree stock, timber and business opportunities, including those 'downstream' of the woodland affected. The impact is also likely to be environmental, including habitat and species loss, carbon loss, run-off, pollution and smoke. There are social impacts too; these range from health threats to forestry workers and visitors to impacts on power lines, transport networks, access routes and other infrastructure.

Woodland habitats that are considered 'high risk' for wildfires are young coniferous stands of pine, spruce or fir, and plantations of eucalyptus or cypress. Broadleaved, mixed and yew woodlands are usually considered 'low-risk' habitats, although young or newly planted broadleaves will be at risk of substantial damage if there is combustible ground vegetation. However, risk assessment must take into account adjacent habitats and land uses, as wildfire often spreads into woodland, having started outside or in open areas within a wider forest landscape. Two particular factors increase wildfire risk: heavy recreational use during warm, dry periods, which can increase the risk of ignition from discarded cigarettes and barbeques, for example; and outbreaks of pests or diseases, which increase foliage, branch or tree mortality and the volume of dry flammable material, which can act as a fuel. The accumulation of ground vegetation and its litter, and standing or fallen deadwood, including distributed brash and log stacks, can provide fuels and increase the risk from fires. However, it should be noted that deadwood is an important component of a properly functioning forest ecosystem and it plays a key role in sustaining biodiversity and soil fertility (see Forestry Commission Practice Guide *Managing deadwood in forests and woodlands* for information and guidance).

Adaptation measures can help reduce the incidence and impact of wildfires in forests and woodland (see Identifying and selecting adaptation measures on page 19). Risks from wildfire can be reduced through a combination of planning, cooperation with neighbouring land holders, and forest design and infrastructure measures. If your woodland is at risk of wildfire, now or in the future, we recommend you consult the Forestry Commission Practice Guide *Building wildfire resilience into forest management planning*. The changing fire risk in Swinley Forest and Crowthorne Forest in the southeast of England (see Case study) was reassessed after a significant wildfire during 2011. As a result, adaptation measures described in the Practice Guide have been implemented into management plans to reduce the risk of wildfire.

Pest and disease risks

Pests and diseases are key determinants of plant growth, woodland species composition and tree productivity. The changing climate will increase the risk to trees and woodlands from pests and pathogens. Many pests and pathogens are likely to increase, either through the direct impact of climate on their abundance or distribution, or the indirect effects of climate on trees that could affect growth and increase the susceptibility of trees to attack. Changing patterns of precipitation and warmer temperatures are expected to lead to an increased number of water-stressed host trees. This could be from seasonal water logging, and/or extended or more severe drought periods in summer. Together with changes in international trade and movement that provide a pathway for pests and pathogens to move from country to country, these are very likely to increase the number and severity of pest and disease infestations in the future and may make damage more difficult to manage. Pests and pathogens often interact, for example, a beetle pest may transmit a fungal pathogen, as in the case of Dutch elm disease. Large-scale damaging outbreaks are possible, as is evident from the recent countrywide ash dieback and *Phytophthora ramorum* outbreaks (Figure 7).

Disease risks

A wide range of factors influence the abundance, distribution and impact of pathogens that attack trees. Changes in temperature, precipitation, soil moisture and relative humidity have all been shown to have a direct influence on the growth, dispersal and survival success of many pathogens. Most pathogens currently affecting UK forests are native or endemic and usually only cause low-impact damage or sporadic significant episodes. Temperature and moisture are key to the development of epidemics, so the changing climate is likely to affect pathogen risk. Milder winters will increase the ability of some pathogens to survive over winter in the UK, for example, some frost-intolerant, root-attacking *Phytophthora* species. Pathogens that infect foliage or that have an aerial phase of the life cycle will be especially responsive to climate change. Warm and wet springs will favour the growth of species such as *Phytophthora ramorum* (Figure 7), and storms with high rainfall and strong winds will provide more opportunities for long-distance dispersal.

By contrast, climate changes may have little direct impact on the growth and sporulation of ubiquitous root-attacking and decay fungi such as *Armillaria* and *Heterobasidion* but drought stress is likely to predispose trees to attack by these pathogens and increase mortality. Likewise, latent pathogens that infect plants, but which can be asymptomatic for years, are predicted to become more damaging as opportunities for activation and invasion increase with more water-stressed hosts.

An example of how one landowner is managing changing disease risk is presented in a Case study to support this Practice Guide. 'Acute oak decline in Bell Coppice' is available at **forestresearch.gov.uk/adapting-forest-management-to-the-changing-climate**

New threats such as chestnut blight and pitch canker, which have previously been viewed as southern European problems, are extending their northern range as the climate warms. Trade pathways between countries inevitably provide opportunities for such pathogens to arrive in the UK, and a changing climate is increasingly likely to favour establishment and secondary spread. Bacterial pathogens of forest trees have a growing profile and are likely to feature more in the future. For example, bacteria are involved in the acute oak decline complex that affects mature oaks in the UK, and the bacterial pathogen *Xylella fastidiosa* causes various diseases in trees, ranging from widespread mortality of olive trees in southern Italy through to slow declines and leaf scorch diseases of oaks, elms and Acer species in North America.

Figure 7 *Phytophthora ramorum* can infect a range of host species. The disease causes particularly damaging infections in larch trees, as shown here at Loch Trool in Galloway.

Insect pests

The abundance, distribution and impact of forest insect pests are determined by complex interactions between climate, food availability, natural enemies, dispersal opportunities and competitors. Insects are cold-blooded, so the temperature of their environment directly influences their rate of development, generation time and survival. With a changing climate, warmer temperatures may therefore enable some species to have more generations each year, extend the period over which they are active, or extend their distribution range. For example, the oak processionary moth (*Thaumetopoea processionea*), introduced to London and the surrounding area, is likely to extend its range as temperature increases (Figure 8).

Changing temperature and precipitation patterns are also expected to have indirect effects on forest pests. For instance, warmer temperatures and more frequent droughts will lead to increased water stress in host trees and potentially an associated reduction in their defences. Other indirect effects on the pests may include altered relationships with natural enemies or competitors, or with control measures. For example, the pine weevil, *Hylobius abietis*, is expected to respond to warmer temperatures with a shorter life cycle in the north and west of the UK. This could allow shorter fallow periods between harvesting and replanting, alleviating its impact and reducing insecticide use.

Different groups of insects are likely to be influenced in different ways, according to key aspects of their ecology and life cycle. Aphids, such as the green spruce aphid *Elatobium abietinum*, are likely to benefit from warmer temperatures, allowing them to produce more generations of offspring each year and increase their overwintering survival. Conversely, more intense periods of rainfall might increase the mortality of these insects, which are exposed on the plant surface. Overall, however, their abundance and the damage they cause are likely to increase under climate change.

Bark-boring beetles could similarly benefit from warmer temperatures, reducing the generation time of some species, while drought stress on trees and more frequent extreme

Figure 8 The caterpillars of the oak processionary moth feed on the leaves of several species of oak. Large populations can strip whole trees bare, leaving them more vulnerable to other pests and diseases, and to other stresses, such as drought.

!

Up-to-date information on tree health and pest and disease outbreaks can be found at **observatree.org.uk**. You can use TreeAlert to report tree health concerns at **treealert.forestresearch.gov.uk** (**treecheck.net** in Northern Ireland).

weather events such as windstorms would increase the availability of breeding material for the insects (e.g. spruce bark beetle *Dendroctonus micans*, pine shoot beetle *Tomicus piniperda* and oak pinhole borer *Platypus cylindrus*). Increased damage from defoliators could also make host trees more vulnerable to secondary attacks from bark beetles. Damage from this group is therefore expected to increase under climate change.

Many defoliators such as the larvae of butterflies and moths (Lepidoptera) are adapted to feed on newly flushing leaves. Climate change has the potential to cause a mismatch between their emergence and budburst leading to greater larval mortality, but selection pressure and a short generation time means that species affected are likely to track such changes in host phenology and synchronise their emergence with the earlier budburst of the host tree. Other species of Lepidoptera and sawfly may benefit from warmer summer temperatures through more rapid generation times or range expansion. A review of insect pests and forest pathogens that affect forests in the UK, or may do so in the future, is presented in the Agriculture and Forestry Climate change report card 7, *Insect pests and pathogens of trees*.

Forest Research gathers information about tree health in the UK. We recommend you check the latest information for disease and pest outbreaks in the Tree Health information on the Observatree website (TreeCheck in Northern Ireland), together with the Forest Research and Defra websites, and seek professional expertise in assessing tree health risks. Sourcing planting stock from suppliers accredited with certified schemes such as 'Plant Healthy' will offer an additional degree of quality assurance to assist with pest and disease control (see Further reading and useful sources of information on page 43).

Mammalian pests

Milder winters, fewer and shorter cold spells, and longer growing seasons will contribute to an increase in woodland mammal populations. This increases the risks of damage to trees and poor establishment and regeneration of woodlands caused by deer and grey squirrels. For example, population densities of grey squirrels are expected to increase due to improved food availability because warmer weather stimulates seed production and an increase in survival rates as a result of milder winters. Oak damage from grey squirrels in lowland areas of the UK is expected to increase, particularly as the area of woodland increases and new woodland matures.

> **!** We recommend frequent monitoring of vegetation, seedlings and young trees for signs of browsing, bark stripping and other damage by mammals in order to assess the risk.

Increasing wild boar and feral pig populations may reduce regeneration in species with seeds which they eat (e.g. oak, beech and hazel), although the increasing ground disturbance may stimulate regeneration of some other small-seeded species (e.g. birch). Seed predation by small mammals, particularly the wood mouse (*Apodemus sylvaticus*), has also been identified as a factor potentially influencing the success of woodland creation using direct seeding (Figure 9). More information can be found in the Forestry Commission Research Note *Species preference of small mammals for direct-sown tree and shrub seeds*.

Recent research using national observations of deer damage in forests and woodlands has provided a tool to assess herbivore impact, and to investigate the likelihood that a forest will be damaged by deer in different locations across the UK, according to regional, landscape and local factors. At the management plan level, guides are also available on how to assess the risk of herbivore impact at particular sites. See forestresearch.gov.uk/research/impacts-of-large-herbivores-on-woodlands for more information.

> The Case study on 'Kinveachy Caledonian Pinewoods' includes an example of managing mammalian pests in a changing climate: **forestresearch.gov.uk/adapting-forest-management-to-the-changing-climate**

Figure 9 Assessing the risk of seed predation is particularly important for regeneration; milder winters are expected to increase seed production in some tree species and increase woodland mammal populations.

Drought risk

Prolonged dry periods can cause water stress in plants, which causes a number of physiological changes that may result in reduced tree growth, crown dieback and even tree death. The timing is key to the impact: dry springs may affect the current year's growth, late summer droughts may affect the next season's growth more. Repeated droughts may have a cumulative effect, leading to growth reductions several years later. The impact of drought conditions is exacerbated by the hotter weather that frequently occurs at the same time, as warmer air increases the evaporative demand for water. The projected warmer summer conditions in the future are therefore likely to increase water stress, even if rainfall does not change, but summers are projected to become drier across most of the UK, with the largest reductions in southern England (see Table 1 on page 9).

Site soil characteristics are key factors determining drought risk as they determine the water availability for trees and other vegetation. Shallow, light-textured and freely draining soils hold less water than deep, heavier soils, and therefore trees growing on shallow, lighter soils are more prone to water stress and drought impacts. However, rooting depth is also an important factor; ground vegetation and shallower rooting shrubs may be more affected than deeper rooted trees. Newly planted trees will be particularly vulnerable to droughts, especially those on exposed open sites; smaller, more fragmented woodlands are more likely to dry out than extensive areas. In addition, trees growing on soils that are deep, but poorly drained so that they are waterlogged in winter, may have shallow rooting zones, and therefore may be at risk if upper soil layers dry out in summer, even if there is water in deeper layers. The projected changes in rainfall seasonality with wetter winters and drier summers may increase the drought risk in these situations.

Tree species differ substantially in their drought tolerance, reflecting adaptation to their native habitats. For example, beech, birch and sycamore are more sensitive than hornbeam or native oak species, and species such as Douglas fir and western hemlock are more tolerant of drought and show lower susceptibility to stem cracking than Sitka spruce. Differences in drought tolerance can also exist between different local populations (provenances).

While it is a common observation that drought conditions reduce tree growth, they can also impact the commercial value of conifer species by increasing the incidence of stem cracks,

!

Use the Forest Research decision-support tool ESC (see page 41) to assess moisture deficit in relation to the current tree species and/or guidance on tree species selection. It is important in forest planning to understand differences in susceptibility to drought among different tree species and provenances to make informed choices.

negatively impacting the health of the forest and structural properties of the wood. Older, slower growing and veteran trees are more likely to be affected by drought than younger ones. Because the effects of drought differ with species and tree age, this may result in changes to stand species composition and age structure.

Drought conditions can lead to increased mortality if drought is prolonged, severe or repeated; in addition, water stress can also predispose trees to damage from pests and diseases. For example, several diseases are likely to increase in frequency and severity for drought-prone forest and woodland trees in Scotland.

Preparing for increasing drought risk was the most important factor influencing adaptation measures in Alice Holt Forest in southern England. This Case study (forestresearch.gov.uk/adapting-forest-management-to-the-changing-climate) explains how drought risk influenced the selection of adaptation options, resulting in changes to management in relation to operations, silvicultural systems and species choice.

The Forest Research tree species suitability tool, ESC (Ecological Site Classification), can be used to calculate moisture deficit and soil moisture regime for your site, and indicate its suitability to support a range of tree species into the future, depending on their sensitivity to moisture deficit. It can also assist decision-making for new planting by providing information to compare the suitability of different species on a site, taking account of future conditions and the sensitivity of different tree species to moisture availability.

Frost risk

Most native woodland species will be tolerant of the cold temperatures that typically occur over winter in UK conditions. Introduced tree species that are planted widely will also have been selected for appropriate tolerance for typical past climate conditions. Extreme cold periods can damage plant tissues or lead to tree death or may affect tree growth, making trees more susceptible to disease. Trees are particularly vulnerable to cold temperature episodes if they occur outside the period that trees are dormant or hardened. In particular, frosts may cause damage to sensitive new growth or de-hardened shoots in spring or early summer (late frosts), or to the current year's leaves in autumn (early frosts) before leaf fall or shoot hardening.

> **!** Care should be taken when using frost-sensitive species, provenances or genotypes, and they should be avoided in frost-prone or vulnerable locations. Where frost-prone tree species are planted, we recommend limiting them to be a component of a forest or woodland, along with less sensitive species.

The warming climate in the UK has already reduced the frequency and severity of frosts and increased the length of the frost-free season in many areas, and this trend is projected to increase (Table 1). It has been widely recorded that there has been a general trend of earlier budburst across the UK in recent decades in many tree species. However, there is a trade-off between earlier budburst with the potential for an extended growing season and the risk of damage from a late spring frost. If bud-break or shoot extension starts earlier in the season or growth continues until later, then the risk of damage from frosts may not decrease and might even increase. The risk will also depend on whether minimum daily temperatures increase consistently, or whether they become more variable so that at critical periods in the year frosts will still occur, which is presently unclear.

Frost risk tends to be highest inland and lower in coastal areas but is also determined by the local microclimate. For example, cold air drainage from exposed north-facing slopes is well known to create frost pockets or hollows; this can be exacerbated if there are light, sandy soils where the surface cools more rapidly.

Flooding and waterlogging risk

Many parts of the UK are seriously impacted by flooding and the frequency of floods is expected to increase due to climate change. Forests and riparian woodland can contribute substantially to reducing downstream flood risk due to their potential high-water use and high surface roughness, slowing both run-off and the peak flow in streams and watercourses (Figure 10). However, these benefits are dependent on healthy woodlands and the trees themselves may be damaged by an increase in soil wetness and flooding.

Soil waterlogging restricts the supply of oxygen to tree roots and prevents their normal function in absorbing water and nutrients. Longer lasting flood conditions typically have more impact on tree growth and survival, by prolonging these stresses. Exposure to flood conditions during the dormant season is less damaging for most species than during the growing season in spring and summer. For flood-intolerant tree species, flooding and prolonged waterlogging can:

- Damage trees and reduce growth, especially for roots and sometimes for shoots, depending on tree age and condition.
- Lead to soil compaction and restrict rooting depth.
- Damage soil health and make trees more vulnerable to infection and disease, e.g. *Phytophthoras*.
- Increase vulnerability to secondary impacts such as windthrow due to reduced anchorage.

Care in species choice, soil management and drainage, woodland design, placement and management can mitigate these effects. They can also help to secure woodland benefits for reducing downstream flood risk. More information on working with natural processes to reduce flood risk is available in a UKFS Practice Guide *Designing and managing woodlands and forests to reduce flood risk* (publication date 2022).

Figure 10 Prolonged waterlogging can increase vulnerability to secondary impacts such as windthrow.

Risks to ancient, semi-natural and native woodland

All types of woodland will be affected by the changing climate, including ancient, semi-natural woodlands. The main impacts will be changes in where habitats or species are found, alterations in vegetation composition and age distribution and structural changes. In these woodlands tree species change is more likely to occur naturally, rather than be a result of planting. For example, species adapted for cooler conditions may alter their range to higher elevations in the uplands and species limited by low temperature at the northern edge of their range may extend further north. Changes in tree species composition are likely; for example, species that like warmer conditions might set seed more often and regenerate (e.g. small-leaved lime and hornbeam). The age structure of stands will be affected if there is an increased frequency of natural disturbance events, such as increased mortality from longer droughts, increased wildfire in fire-prone drier habitats, or more wind damage to stands on wetter soils in winter.

Changes in the whole vegetation community structure are likely because of altered plant competition caused by changes in light from increased leaf area and earlier leafing, increases in growing season temperature, and drier soil conditions in many woodland types during the summer months. It will therefore be important to consider climate change in the management of ancient, semi-natural and native woodland and to develop management and contingency plans to deal with impacts. It may also be necessary to adjust the management objectives for the site if, for example, species suitability changes. It should be possible to identify opportunities to promote different species or habitats rather than simply accept the loss of features of interest. Such alterations may need to be reflected in the definition of favourable condition for a designated site (e.g. Site of Special Scientific Interest), in which case the appropriate national conservation body should be consulted.

Where priority is given to important or protected habitats, guidance from the statutory nature conservation agencies will set out what is known about the potential sensitivity of woodland habitats. For example, refer to the second edition of Natural England and RSPB's *Climate change adaptation manual: Evidence to support nature conservation in a changing climate*, which describes the potential sensitivity of a range of habitat types, including the main woodland habitats.

Risk summary

Detailed climate analyses show that the UK climate has already changed over the past 50 years; although noticeable, the changes so far are quite small compared with those that are projected for the next 50 years (see page 7). Given the longevity of woodland, managers need to be planning and adapting practices to reduce risks and to benefit from any opportunities. Some risks described above are well understood, and there are tools and information available to support assessments. However, there are likely to be new or little understood risks, particularly in the longer term, and some risks may occur in new combinations. This emphasises the need to view the Adaptation framework (Figure 2) as a continuing approach, reassessing as both the woodlands and the climate changes. New and unfamiliar risks also suggest that it will be important for individuals and the forestry and woodland management sector as a whole to share knowledge and experience, and to pool information on what works and what does not, in different situations. Furthermore, sharing information would support efforts to better understand the financial implications of taking adaptation actions.

Identifying and selecting adaptation measures

Forest and woodland managers should consider their management objectives together with the assessment of the risks from climate change in identifying potential adaptation measures. Table 2 lists possible measures but is not exhaustive and these need to be implemented appropriately in order to be effective. More details of the measures are described in the rest of this section.

A range of adaptation actions that are appropriate for the particular site and the management objectives should be considered in order to reduce risk and vulnerability and to benefit from any potential opportunities. In addition, the local context and role of the woodland in the wider landscape should be assessed. For example, could woodland change affect run-off and stream flow, could it improve the connectivity between habitats, or could it instead break up habitat corridors? More information about adaptation of specific protected woodland habitats in the UK can be found in guidance from the statutory nature conservation agencies, for example, in Natural England and RSPB's *Climate change adaptation manual*. Adaptation measures that will reduce the most immediate and greatest risks should be prioritised. In addition, while planning usually considers the 'average climate change', it is important to plan for changes that are more extreme (see page 7). Note also that climate projections for a broad period in the future are not predictions of what will happen at a particular date; there is uncertainty over the time course as well as the magnitude of climate changes.

Table 2 Possible adaptation measures for selected climate change risks.

Measures	Risks					
	Windthrow	Wildfire	Pest/disease	Drought	Frost	Flood
Increasing tree species diversity	●	○	●	○	○	○
Creating mixed species stands	●	●	●	●	●	– –
Choosing tree provenance	– –	– –	●	●	●	– –
Using natural regeneration	●	✖	○	○	○	– –
Carrying out thinning operations	●	●	○	●	– –	– –
Diversifying structure	●	○	●	●	○	●
Considering forest and woodland design	●	●	●	– –	– –	●
Establishment and management	●	○	○	●	– –	– –
Adapting infrastructure	●	●	– –	– –	– –	●
Contingency planning	●	●	●	○	○	●

● Measure likely to reduce risk if applied appropriately. ○ Measure may reduce risk but about which less is known.
✖ Measure unlikely to reduce, and may exacerbate, risk. – – Lack of information or unknown.

Increasing species diversity

Risks reduced					
Windthrow	Wildfire	Pest/disease	Drought	Frost	Flood
●	○	●	○	○	○

The UKFS advises on the maintenance or establishment of a diverse species composition. The Guidelines offer advice on the use of single and multiple species, the balance of allocation, and encourage realisation of opportunities to further diversify species composition (Figure 11). Increasing the diversity of tree species can take different forms, such as changing tree species or the dominant species in an area, increasing the overall number of different tree species, mixing species in stands (see the next section) or making use of different provenances (or using improved stock). There are strong reasons to diversify tree species composition, as it may:

- Reduce wind, wildfire, pest and pathogen, drought and frost risk if different species have different vulnerabilities to these risks.
- Improve market opportunities for timber and wood fibre (i.e. provide a greater diversity of products).
- Increase the productivity of some mixed species stands compared with monocultures of component species (see the next section).
- Enhance biodiversity and improve amenity value.
- Improve population connectivity between currently under-represented tree species (especially native tree species).

In addition to these silvicultural and management benefits, the presence of another species that can replace a service or function previously provided by one species is known in ecology as 'functional redundancy' so that higher levels of redundancy should provide greater resilience. Some woodlands are dominated by one tree species either because of present or past management objectives or through particular site characteristics. The dominant species may have a significant influence on composition and functioning, acting as a keystone resource provider. The loss of the dominant tree species in woodlands with limited functional redundancy may therefore result in a cascade of loss of associated species and functions.

Figure 11 A range of tree species with a diversity of functions supports multiple management objectives at Loch Ard, Loch Lomond and Trossachs National Park.

Management of woodlands with limited species diversity should include plans for substantial change, such as increasing tree diversity to improve stand resilience to natural disturbances including windstorms, wildfire risk, insect herbivores and fungal pathogens and drought.

The extent to which tree species diversification can be achieved will depend on management objectives and site conditions. The Forest Research tree species suitability tool ESC (see page 41) provides guidance and will help to identify alternative species; given the need to diversify, choosing those with slightly lower suitability or timber yield potential should also be considered.

Key points for diversifying tree species

- A wider number of tree species in a stand is a prudent component of a management strategy. This may involve increased use of 'emerging' tree species (species that exhibit potential for more frequent or wider use).
- More than one tree species should fulfil the role of 'keystone' resource provider, aligned with the main management objectives of the woodland.
- It is important to consider the risks of introducing species that are well suited to current conditions but may become unsuitable in future conditions.
- Sourcing seed from registered seed stands or seed orchards is recommended if the priority is timber production. Registered seed stands produce trees with superior timber, form and growth properties.
- Nurseries are developing stock with the aim to improve climate resilience, e.g. breeding for drought resistance. Incorporating an element of these adds diversification and resilience within the same species.
- There may be a limited seed supply for less commonly used species; emerging conifer species often take longer to reach a sufficient height to be used as planting stock and this can increase costs.
- Develop relationships with nurseries and discuss requirements in advance.
- Where considering exotic tree species, ideally choose species that have been the subject of provenance testing and trials.
- Use of UK sources of seed of exotic species is likely to provide closer adaptation of trees to present UK conditions, but it should be recognised that future climate changes may mean other seed sources may be better suited.
- Source 'Plant Healthy' certified stock (planthealthy.org.uk).

> **!** When considering how to increase diversity, consider options for choosing different provenances, structural, scale and configurations, as set out in the next sections.

> A Case study example of work to diversify tree species is given in 'Climate ready forestry in Queen Elizabeth Forest Park': **forestresearch.gov.uk/adapting-forest-management-to-the-changing-climate**

Key points for diversifying woodland at the stand scale

- Include tree species with a diversity of traits and functions that will support management objectives (in combination), rather than a sole focus on increasing the number of tree species.
- Underplanting and mixed species restocking can improve resilience, not only to climate change but also to other threats, such as pest and disease outbreaks.
- Plantings of intimate species mixtures are likely to be more resilient to pests and pathogens (see next section).
- In forests that are managed by clearfell, diversifying species across different stands creates a matrix structure, which is more resilient both ecologically and for timber supply.

Forest Research provides information to support species and provenance selection. Descriptions of the natural distribution range, species characteristics and site and climatic preferences are available for a wide range of tree and shrub species. A searchable database and a list of places where you can visit different species examples is available from forestresearch.gov.uk/tools-and-resources/fthr/tree-species-and-provenance.

Creating mixed species stands

> Information about the benefits of stand diversification using natural regeneration is summarised in Forestry Commission Research Note *Converting planted non-native conifer to native woodlands.*

Mixing species within stands is not a new practice, particularly for planting native woodlands. Traditionally in the UK, conifer 'nurses' were used during the establishment of broadleaves, and conifer mixtures were used for nutritional purposes on sites with poor soils. Mixtures include intimate or random mixtures, row or line mixtures, group mixtures and mosaic mixtures. In recent decades the use of mixtures has been limited but they are being recommended as an important adaptation measure offering insurance against unknown future risks, so that if one species fails, other species provide a continuing stand structure. The new concept of 'forest development types' encourages greater use of mixed species stands and a wider variety of stand structures (forestresearch.gov.uk/tools-and-resources/fthr/forest-development-types).

Past experience of species mixtures is important to inform decisions about the configuration of future mixed species stands (Figure 12). In upland areas of the UK, there is a substantial area of mixed conifer–broadleaf forest, with Sitka spruce and Scots pine being the most common conifers and birch the most common broadleaf in these mixtures. In lowland England mixtures are fairly common, occupying nearly a third of the public forest estate; the most common mixture is conifer–broadleaf followed by conifer mixtures, with broadleaf mixtures less common.

Key points for creating mixed species stands

> Choosing the right species for mixtures needs to consider carefully their particular growth characteristics; guidance and a tool are available from **forestresearch.gov.uk/publications/establishing-robust-species-mixtures**

- The compatibility of the proposed tree species in a mixture must be considered (e.g. growth rates, shade tolerance, rooting depth).
- UK experience of species compatibility may change under future climate conditions.
- Choice of mixture type should be informed by:
  - The desired type of resilience (e.g. reduced susceptibility to fire or to root pathogen infection, which would favour an intimate mixture over a group one).
  - The intended duration of benefits from mixed species, which affects how compatible and complementary tree species in intimate mixtures need to be (e.g. temporary benefits would favour nurse crops, but these would not be appropriate long term).
  - Opportunities for natural regeneration and presence or absence of a suitable seed bank to diversify the stand.

Figure 12 Experience of growing different tree species in the UK can inform which are compatible in different settings but this may change under future climate conditions.

Choosing tree provenance

Risks reduced					
Windthrow	Wildfire	Pest/disease	Drought	Frost	Flood
– –	– –	●	●	●	– –

The provenance of tree seed or stock refers to its geographical origins. Choosing the appropriate tree species and provenance for the site characteristics and local climate is a key management decision. However, provenance choice for a changing climate is complex, uncertain and the approach is likely to be different for sites where the main objective is timber production compared with those with primarily conservation objectives. Long-term trials and demonstrations have been started to further develop the evidence base to assist provenance choice.

Where timber production is important, the UKFS advises on the consideration of a wider range of tree species than has been typical of past planting and to consider the use of planting material from more southerly origins. This use of planting material from more southerly origins is a type of 'assisted migration', which can involve both native and non-native species. Provenances of native species from more southerly latitudes have been planted in some parts of the UK and have been found to outperform local provenances for height growth and yield during early growth. In general, southerly provenances will be adapted to hotter, drier conditions that are now likely to occur. However, survival and stem form can be compromised if the transfer distance is too large, or if the transfer is made from an area with a continental climate. There is some evidence that southerly provenances show reduced susceptibility to drought but also an increased risk from frosts.

However, the merits of such assisted migration require further research. Using material from a currently warmer or drier climate may result in maladaptation to site factors other than climate alone (e.g. soil conditions and microbiota). While growth of local provenances may not be as good as those from warmer locations (due to conservative adaptation to the local growing conditions), this may confer hardiness and reduce frost risk. Different tree species react in different ways to such transfers and comparative advantages between provenances may change when a new climate or other stresses are imposed. Populations of tree species

Figure 13 Oak of a more southerly provenance, such as the Loire Valley (pictured here), can show improved growth in southeast England.

The Bicentenary Project Case study includes an example of assisted migration of native species in a small wood within a large family-owned estate. Several adaptation measures have been implemented to increase resilience and inform future adaptive practice.

native to the British Isles contain high levels of adaptive diversity, which could enable genetic adaptation to climate change. Natural regeneration should be encouraged to promote evolutionary adaptation. In exotic species, genetic adaptation can occur relatively quickly, with differences in performance being detected between the first and second generations following introduction. Therefore, regenerating a site using locally produced seed from existing plantations could allow continuous genetic adaptation at a site.

Irrespective of whether seed is sourced locally or from more southerly locations it is best to source these from stands that are classified as 'Selected'. Selected categorisation is defined in the Forest Reproductive Material (Great Britain) 2002 Regulations and the OECD Forest Seed and Plant Scheme Rules and Regulations. Selected seed stands have been identified as superior for tree form traits such as straightness and absence of forking. Where there has been a breeding programme in place in the UK, seed from this should be preferred when timber is the main objective. If improved stock is unavailable, for some species there can be growth benefits from collecting seed from stands prior to felling to use as planting material back onto the same site.

For sites where the objective is more focused on habitats and conservation, assisted migration of provenances may not be suitable. The UKFS advises that it is generally best to use well-adapted local or regional origins from similar elevations when planting native species and native woodlands.

Key points for choosing tree provenance

- Consider the advantages and disadvantages of using material (i.e. seed and seedlings) from a southerly climate and what is known about the site conditions.
- Check for the latest information, including that for individual countries, and how climate change is having an impact on the particular species further south before deciding; note that there is some risk attached to any choice of planting stock.
- The extent and timing of change in climate conditions varies across the UK, so the balance between any risks in introduced planting material and benefits in being better suited to future climates varies, e.g. in southern and eastern England choosing planting material for anticipated increased soil moisture constraints is likely to be important, while in Scotland ensuring material has appropriate bud set and frost tolerance may be the key factor.
- Regenerate existing plantations from locally produced seed to promote evolutionary adaptation on a site.
- Consider the options for using those native species that are well adapted to likely future conditions.
- Shortage of appropriate planting stock can be a problem; advance notice of requirements can help to enable nurseries to prepare a sufficient supply of material.
- Where timber is the main objective, seed should be sourced from breeding programmes, and if this is not available, from the Forest Reproductive Materials 'Selected' category of stands.
- Where planting exotic species, ideally use stock which has undergone provenance testing and, subsequently, choose UK sources of seed to encourage the development of genotypes adapted to UK conditions.

A range of resources on genetic considerations and choosing provenance are available, please see Further reading and useful sources of information (page 43) and the supporting web pages for this Practice Guide (forestresearch.gov.uk/adapting-forest-management-to-the-changing-climate).

Using natural regeneration

Risks reduced					
Windthrow	Wildfire	Pest/disease	Drought	Frost	Flood
●	✖	○	○	○	--

Natural regeneration can refer to seedling establishment either under existing or recent tree cover and in areas where there has not been recent woodland. The latter is sometimes referred to as 'natural colonisation' if it depends on wider dispersal of seed from local seed sources and may be useful for woodland expansion. Naturally regenerated trees in either situation are likely to be better adapted to the site soil and recent climate conditions than their parents and may be better adapted than planted nursery stock. Using natural regeneration may encourage adaptation through natural selection and should therefore be considered where appropriate, so that species adapt to current local site conditions and to the changing climate (Figure 14).

Use of natural regeneration may lower the risk of wind damage compared with planted stands (Figure 15), due to the development of more even root systems, and by reducing wind loading if the stand structure is uneven. The presence of an existing naturally regenerated understorey within a stand can also allow faster recovery of the stand following windthrow. Drought risk is likely to be reduced because of the better rooting in regenerated trees, compared with nursery stock, which may suffer root damage during transfer. If the regeneration is within stands, the shade and shelter provided may also protect from drought and frost risk. However, stands with a large amount of understorey vegetation resulting from natural regeneration may have a higher risk of fires spreading to the crowns than uniform-aged stands due to the vertical continuity of vegetation that can provide fuel.

Natural regeneration can reduce establishment costs depending on the availability of a suitable seed bank. It may be necessary to thin stands to allow seedling recruitment, and there may be increased management requirements including ground preparation and measures to protect seed and seedlings, more weeding and subsequent thinning. There may also be increased harvesting costs due to the complexity of stands and the larger assortment of timber sizes. There are also practical constraints to achieving successful natural

!

Resources on different aspects of regeneration of broadleaved trees and shrubs are available from **forestresearch.gov.uk/research/lowland-native-woodlands/natural-regeneration-of-broad leaved-trees-and-shrubs**

Figure 14 A number of climate risks may be reduced in naturally regenerated stands; however, the decision to use natural regeneration or not requires careful consideration of a range of factors.

Figure 15 Use of natural regeneration may lower the risk of wind damage compared with planted stands and allow faster recovery following a storm event.

regeneration that need to be managed, including variability of seed production, seed viability, seed predation by rodents and birds, within-stand light availability, weed competition and browsing of seedlings by deer.

Key points for using natural regeneration

- Some risks may be reduced in naturally regenerated stands, including wind risk, pests, pathogens, drought and frost. However, if trees have been removed from a site because of previous plant health problems, natural regeneration may not be appropriate to avoid reinfection.
- It is important to manage the constraints to successful regeneration, including ensuring sufficient seed production, the desired range of species, limiting seed predation, suitable light availability and adequate control of herbivore browsing.

Carrying out thinning operations

Risks reduced					
Windthrow	Wildfire	Pest/disease	Drought	Frost	Flood
●	●	○	●	– –	– –

Thinning may be a useful management operation to consider for reducing climate change risks (Figure 16). Changes can be applied within a rotation to accelerate adaptation ahead of end-of-rotation measures, such as changing the species composition of a woodland using underplanting or enrichment planting, or by stimulating natural regeneration.

Alternative thinning regimes have been adopted by forest owners to try to better manage a range of risks, sometimes in combination with other measures. For example, thinning can be used to reduce the impacts of Dothistroma needle blight. Crown thinning increases air movement within the canopy and reduces humidity, which, combined with lower basal areas, can reduce rates of infection. Heavy, early thinning has been trialled in Thetford Forest to reduce mortality from needle blight, in combination with underplanting of shade-tolerant 'emerging' species to adapt the forest composition over time.

Wind risk increases immediately following stand thinning, as the wider spacing exposes trees to higher wind speeds. However, as wind risk is directly related to tree size, the earlier that thinning is conducted, the smaller the increase in risk. Following thinning, trees adjust to their new wind regime by strengthening stem and roots, and, within a few years, trees can regain, and potentially improve on, their initial stability.

Wildfire risk can be reduced by thinning, particularly at early stages of stand growth, and can be used in tandem with high pruning and other management operations. However, the resulting brash needs to be managed appropriately to balance the need for deadwood, which has an important role in supporting a properly functioning forest ecosystem (see Forestry Commission Practice Guide *Managing deadwood in forests and woodlands* for further information) and creating a fuel load that could increase the risk of wildfire.

Figure 16 Thinning operations can provide opportunities to reduce climate change risks within a rotation.

Courtesy of Forestry England

Thinning is likely to reduce the risk of growth reductions or mortality during drought periods by increasing water availability to the remaining trees. However, the result is dependent on local conditions and the intensity of thinning. Thinning the overstorey has been shown to increase air temperature and reduce humidity in the canopy and can therefore increase tree water loss rates. It may also promote ground vegetation growth. Heavy thinning could therefore result in drier soil and reduced tree growth in dry weather conditions. Conversely, thinning could increase soil water availability by allowing more rainfall to reach the ground. For these reasons, gradual halo thinning around veteran trees may help increase their water supply and reduce water stress, while sudden exposure following a heavy thin could increase water stress. Research in continental Europe has shown that thinning forest stands usually alleviates growth reductions during periods of drought in both conifer and broadleaved plantations, although the mechanisms are different, because the water-use seasonal pattern is different. However, there is little evidence in UK conditions and more research is required to better understand how the different factors of microclimate, stand structure and soil water availability affect water use, growth and drought stress in different forest types under different management regimes (Figure 17).

Key points for carrying out thinning

- As well as encouraging increased tree growth, stand thinning can be an effective measure to reduce a range of risks, including drought, wind, fire, pests and pathogens.
- Some risks, especially windthrow and pathogens, may be most effectively controlled by applying early or pre-commercial thinning.
- Thinning provides opportunities to implement further adaptation strategies, including conversion to continuous cover forestry (CCF), and species change.

Figure 17 Risk from tree diseases such as Dothistroma on pine may be effectively controlled by applying early thinning.

Diversifying structure

Risks reduced					
Windthrow	Wildfire	Pest/disease	Drought	Frost	Flood
●	○	●	●	○	●

Forests with a diverse structure are more resilient and may be better able to withstand some of the risks from climate change compared with even-aged uniform stands (Figure 18). Structural diversification may therefore may be a useful adaptation measure to consider. Structural diversity can be increased both at the stand scale and forest/landscape scale.

Diversifying structure at the stand scale

The structure of the stand is determined by the age and age structure of the trees, the presence of any understorey and the mix (if any) of species or types (broadleaf/conifer, evergreen/deciduous). Management influences all of these, and the key choice for many managers is between even-aged stands and CCF. Although CCF approaches have a number of advantages, discussed in this section, they may not be appropriate or suitable for some sites due to the risks during stand transformation.

On moderately exposed sites, stands managed using CCF techniques may be more wind-firm than even-aged stands, particularly if the structure is complex. Structurally diverse stands have the added benefit that if wind damage to the overstorey does occur, the understorey is already present and can respond quickly. However, stands undergoing transformation to CCF are vulnerable to wind damage, particularly if the transformation is late, and careful thinning is required. Thinning during transformation to CCF may affect water use and soil water availability and thus drought risks, although this will depend on the site conditions and climate (see above section on thinning). In addition, as structurally diverse stands generally have a lower density of mature trees than even-aged stands, it is likely that they recover more quickly from drought than unthinned or dense even-aged stands.

> !
>
> Guidance on assessing site and stand suitability for transformation to CCF and wider management considerations can be found in Forestry Commission Information Note *Transforming even-aged conifer stands to continuous cover management.*

Figure 18 Structural diversity can be increased in different ways: consideration of management objectives is essential to inform selection.

Young planted trees and seedlings from natural regeneration can suffer from high mortality when exposed in restock areas if there are high temperature and drought periods. However, young underplanted trees or naturally regenerated seedlings on a site managed using CCF techniques would be at lower risk due to the shade and shelter afforded by the overstorey. Frost risk to seedlings is also reduced under a canopy managed using CCF approaches.

Structurally diverse stands can improve soil water quality through reduced nitrate leaching and surface water acidification during heavy winter precipitation events, compared with even-aged stands. Furthermore, where stands are established using CCF techniques there is reduced herbicide use during regeneration. This results from avoiding the creation of open restock sites that are heavily colonised by weed growth, and by using the canopy to control competing vegetation.

The adoption of CCF where appropriate can lead to more diverse forest stands, for both species and structure, which would reduce future risks. Although early-stage transformation stands may be no more robust than even-aged stands, more complex CCF structures are likely to be more robust than simple structures. Where transformation to CCF is being considered, the suitability of the site and stand must be assessed. This will require assessing wind risk, soil fertility and weed competition, species suitability, stand structure and quality, the presence of, or likelihood of, achieving natural regeneration, ground conditions, browsing mammals, site access and management restrictions. For example, fencing or other methods of browsing control may be required to ensure establishment of the future understorey trees. The developing understorey, whether planted or naturally regenerated, needs to be carefully managed, i.e. weed control, pest control, supplementary planting and further overstorey operations may be necessary. In addition, dense natural regeneration will typically require respacing to ensure continuing good growth rates and that developing trees are stable. However, it is possible that milder winters may result in poorer regeneration in some species that are close to their threshold for successful seed dormancy break.

The increased use of CCF can help to maintain and enhance the biodiversity of forests, although changes need to be planned at the landscape scale in order to maximise these benefits. The forest design planning process can help achieve this on the public forest estate and other extensive forest areas, as demonstrated in the Case studies 'Transformation to continuous cover forestry in Clocaenog Forest' and 'Demonstrating Adaptation in Alice Holt Forest' (forestresearch.gov.uk/adapting-forest-management-to-the-changing-climate).

Key points for diversification at the stand scale

- When selecting a suitable structure and management system, it is important to consider if it meets the management objectives. Simple structures have one or two canopy layers; complex structures have three or more canopy layers.
- Planning future thinning operations should aim to promote structural diversity.
- Stand restocking can be through natural regeneration or by underplanting.
- Pay particular attention to the light levels in the understorey to ensure that they are adequate for natural regeneration or the growth of underplanted seedlings to succeed.
- If changing species, it is likely that underplanting will be required.
- Monitor the transformation of the stand and adapt management accordingly. It is important that comprehensive records and management plans are kept in an accessible format that allows successive managers to understand and follow the long-term plan.

!

For further information on methods to monitor stand transformation, refer to Forestry Commission Information Note *Transforming even-aged conifer stands to continuous cover management.*

Diversifying structure at the forest and landscape scale

Structural diversification may be achieved at the landscape or woodland scale by diversification of species and stands as described above, including moving to a continuous cover silvicultural system. In a clearfell-restock system, structural diversification at larger scale could also be achieved by adjusting rotation lengths and by planning harvesting and planting to provide an even spread of stand ages, tree sizes and heights. This provides the benefits of even production and maintenance of a range of the benefits across the landscape, and by spreading the risks it leads to reduced overall vulnerability at any point in time. However, there are both benefits and disadvantages of changing rotation lengths as an adaptation measure that need to be considered in restructuring forests or revising management plans. The appropriate decision will again depend on site conditions and management objectives; these might change because of other climate-change drivers, for example, a decision to change to short-rotation forestry to provide woodfuel to mitigate fossil fuel greenhouse gas emissions, or, alternatively, to increase forest carbon stocks.

Shortening rotation lengths

As growing season length extends with a warming climate, and as the atmospheric carbon dioxide concentration continues to rise, tree growth rates will rise, unless limited by other factors (Table 1). The same volume yield may therefore be possible with shorter rotation lengths, which might also be necessary to avoid increasing wind risk from faster growing stands. In addition, reducing rotation length (whether there is increased growth or not) could provide more frequent opportunities to replace tree species or provenances with those better suited to the changing climate. However, if shorter rotations are applied extensively in a forest area without increased growth rates, they would reduce landscape structural diversity and may adversely affect biodiversity.

Lengthening rotation lengths

Extending rotation may be necessary where tree growth rates are limited by various factors such as drought or disease (Table 1). The same volume yield may therefore only be possible by lengthening rotation lengths. Extending rotation lengths in order to increase structural diversity in the landscape can increase the risks from wind (see page 8) and from pests and diseases (page 11). For example, older stands may be more vulnerable to bark beetles and related groups of insects, because resistance against insect attack tends to decline in over-mature trees. Such older trees would also be exposed to a longer period of climate change, further affecting their growth and vigour.

Key points for diversification at the forest and landscape scale

- An even spread of stand ages across a forest or landscape reduces the overall risk at any one time.
- There are benefits and risks involved in either shortening or prolonging rotation lengths, which need to be balanced in any decision to change a rotation length.
- It is important to give careful consideration to tree species, their optimum growth requirements and the risks posed by wind or other threats (including insect pests) before changing rotation lengths.

Considering forest and woodland design

Risks reduced					
Windthrow	Wildfire	Pest/disease	Drought	Frost	Flood
●	●	●	--	--	●

Expanding and creating new forests and woodlands provides an opportunity to design for the future climate and integrate adaptation measures to the plans. Guidance and decision-support tools are available to assist with species choice.

Creating new woodland

Creating new woodland can have multiple social, economic and environmental benefits, and is a key priority for governments across the UK. Creating new woodland is important for climate change mitigation, as it will remove carbon from the atmosphere and provide timber products or biomass to substitute for fossil fuel use in construction materials and energy production. Woodland creation can form part of a wider societal adaptation strategy. For example, woodlands can provide shade and shelter for people or livestock, and they can provide flood protection and reduce soil erosion. The UKFS explains the regulatory framework for woodland creation, and new woodlands will need to be considered by the forestry regulator. The type and purpose of the woodland, its design, management plan and silvicultural details need to be clearly identified and be planned to take account of the impacts of gradual changes alongside changing the frequency of extreme events (see Table 1 on page 9 and the section on Establishment and management on page 34). The management plans should make reference to the main risks from climate change identified and set out which adaptation measures are being applied.

Expanding existing woodland

Larger and better-connected forests and woodlands, with careful species choice in the design, will be more resilient to climate change (Figure 19). There are significant benefits to wildlife where ancient woodlands cover an area greater than five hectares, therefore some forest managers may decide to prioritise activity to enlarge areas of woodland that are smaller than

Figure 19 Forest and woodland design plans should take account of the changing climate and include adaptation measures.

this, in preference to creating new woodland. Although gene flow and species movement would be encouraged, increasing connectivity may also increase the risk of pest and pathogen movement, increasing the spread of invasive species. These benefits and risks are best considered early in the planning phase. Woodland expansion is an opportunity to mix species and prepare for a shift in species range by selecting a mix of ecologically suited species and provenances and matching these to the site as required.

Key points

- The creation of new woodlands will need to be considered by the forestry regulator.
- The site survey, in which you assess soils, wildlife, heritage and landscape impacts, will be particularly important to identify vulnerability to the changing climate.
- Proposed woodland objectives need to be appropriate for the site and take account of different microsites, slopes, soils and hydrology.
- Planning should take account of any existing management plan information for neighbouring woodland areas.
- Forest management plans should lay out which adaptation measures are being applied.
- New woodland types can be considered, particularly in drier areas. You can find information on woodland type suitability in the Forest Research Ecological Site Classification (ESC) and Climate Matching decision-support tools (see links below).
- Woodland planting or natural regeneration schemes and associated access routes and infrastructure should be designed to take account of changing risks, such as wildfire and windthrow.
- Consider methods of establishment. For example, direct seeding improves the opportunity for natural selection and can be a low-cost method of woodland creation but is only appropriate for certain sites. Natural regeneration may be appropriate in some sites (see page 34).
- If an important objective of the new woodland is flood-risk management, refer to guidance on working with natural processes at www.gov.uk/government/publications/working-with-natural-processes-to-reduce-flood-risk. Refer to the UKFS Practice Guide on *Designing and managing forests and woodlands to reduce flood risk* (publication 2022).
- When considering species choice for woodland creation and expansion, consider potential pest and disease risks and ensure that trees are sourced appropriately. The website planthealthy.org.uk supports forest and woodland managers in adopting the Plant Health Management Standard and becoming 'Plant Healthy' certified.
- Brownfield sites can present a unique set of challenges to tree establishment for land regeneration; specific guidance is available to support woodland creation on such sites (i.e. on land that is sometimes referred to as 'previously developed', vacant, derelict or contaminated). Refer to Forest Research Best Practice Guidance for Land Regeneration Note 21 for a summary of land regeneration considerations under a changing climate (forestresearch.gov.uk/publications/best-practice-guidance-for-land-regeneration).

Decision-support tools that incorporate future climate change projections are available, for example, the Forest Research tree species suitability tool, Ecological Site Classification (ESC) (forestresearch.gov.uk/tools-and-resources/fthr/ecological-site-classification), which is applicable to England, Scotland and Wales. Complementary to ESC, the Forest Research Climate Matching Tool shows regions with a similar current climate (across the UK and continental Europe) to the climate projection for any UK location, and gives an indication of the climate that trees are likely to experience in the future. This is designed to help in the selection of material suitable for the future climate. See forestresearch.gov.uk/tools-and-resources/fthr/climate-matching-tool for more information and to access the tool.

Establishment and management

Risks reduced					
Windthrow	Wildfire	Pest/disease	Drought	Frost	Flood
●	○	○	●	– –	– –

Active forest and woodland management is a critical component of climate change adaptation, although without additional adaptation measures 'business-as-usual' management is very unlikely to be sufficient on medium-to-longer timescales. Planned management interventions and scheduled operations provide opportunities for climate change adaptation. Opportunities also arise in the event of a disturbance, such as an extreme weather event or pest or pathogen outbreak. All adaptation measures have management implications, for example, changing to continuous cover systems to reduce pest and drought risk, or changing the thinning intensity of a growing stand to reduce competition for water. Establishment and management practices that can support climate change adaptation include direct seeding, controlling weeds and invasive species and watering and irrigation.

Establishment by planting

Successful establishment of nursery-grown bare-root stock trees requires lifting and planting when trees are dormant. While warming winters might be expected to limit the lifting and planting window, tree nurseries routinely store planting stock in cold stores to allow successful planting regardless of winter temperatures. However, it is still necessary for plants to be lifted when dormant, so mild winters will tend to limit this. Cell-grown planting stock can be lifted and planted outside the periods recommended for bare-root plants, and may have better survival rates in drier conditions, potentially making them more suitable as planting stock as the climate changes.

Establishment by direct seeding

Although the usual approach to tree establishment in the UK is planting, direct seeding (sowing tree seed by hand or machine directly into a seedbed) can be used for woodland creation or regeneration projects (Figure 20). Direct seeding creates more opportunity for natural selection of seedlings for local conditions and can be a low-cost method of woodland creation. However, the success of direct seeding is variable, largely due to predation of seeds by small mammals, especially mice, voles and squirrels. It also requires a large volume of seed, so is not appropriate for those species that produce little seed and may be a problem with those that produce seed infrequently, depending on the timing.

Direct seeding is unsuitable for many sites, especially within established woodlands, as demonstrated in a series of trials on sites in Scotland. However, research trials suggest this approach can be a viable and efficient establishment method for woodland on lowland agricultural land. It has also been shown to work in changing some upland restock sites from conifer to broadleaf (birch, rowan and alder) on less fertile, freely draining sites. The type of machinery typically available on a farm can be used for direct seeding and it has the advantage of creating woodland with a more natural appearance, denser spacing and more rapidly growing trees compared with planted sites.

Detailed advice on establishment by direct seeding is presented in the Forestry Commission Practice Guide *Creating new broadleaved woodland by direct seeding*.

Figure 20 Direct seeding is the process of sowing tree seed in its final growing position rather than transplanting nursery-grown stock. The technique also has great potential for creating large woodlands linking existing areas of ancient semi-natural woodland.

Key points for establishment

- Planting practices may need to change, given milder winters and increasing risk of losses with drier spring and summer conditions.
- Direct seeding can require more technical expertise in ground and seed preparation than planting and requires a large volume of seed, together with an appropriate silvicultural regime.
- Careful site selection, cultivation and species choice and due regard to seed pre-treatment and vegetation management is required to replicate natural seed-fall and regeneration.
- Information about cultivation of soils for forestry may provide useful guidance and background information to consider whether cultivation is appropriate for the site conditions (see Forestry Commission Bulletin *Cultivation of soils for forestry*).

Controlling weeds and invasive plant species

Climate change is likely to affect vegetation competition and the effectiveness of weed control methods; across Europe, there is generally a greater need for weed control in warmer climates. In countries where the climate is similar to the projected UK climate, total herbicide use is typically higher than currently in the UK. Weeds that are better adapted to the new climate will become stronger competitors, while increased drought stress may reduce the trees' competitiveness. Weeds with an extensive range (e.g. bracken, bramble) may cope better with changes in the climate than trees (Figure 21). Many tree species now emerge from dormancy earlier than they did in the past due to climate change. Weed germination may also start earlier in the season and growing seasons for both trees and weeds are likely to be longer. The timing of herbicide applications and their frequency may need to be reconsidered.

Key points for controlling weeds

- Implementing vegetation management should be considered as a priority and the effectiveness of vegetation management should be reviewed on a regular basis.
- The use of alternative silvicultural systems, such as continuous cover forestry, to shelter young trees, can also reduce competition from weeds.
- Consider using sheet mulches to conserve water for plantings on dry sites (i.e. where there is no winter waterlogging) and sites subject to increasing drought conditions.
- Consider if mechanical cultivation methods may be appropriate, for example, if drier summer conditions will make cultivation more effective as weed control than herbicides.

Figure 21 Effective vegetation management is important to relieve direct competition from extensive weed growth, such as at this farm woodland.

Watering and irrigation

Warmer conditions and changes to rainfall patterns are likely to result in drier spring and summer conditions in many locations. In recent years this has already become an issue, with substantial loss of newly planted stock – in the future this risk is only likely to increase. Ensuring adequate water and suitable ground conditions to retain moisture is important for newly planted trees and therefore watering in the field for transplants and irrigation in nurseries may become increasingly necessary, although this will only be feasible at small scales. Alternatively, a change to autumn planting on appropriate sites may reduce drought risk.

In the nursery sector, warmer and drier summer conditions are likely to increase irrigation requirements. One commercial tree nursery in England has already taken active adaptation measures to increase its irrigation capacity by investing in a new reservoir to better cope with drier conditions.

Research to identify drought-tolerant tree and shrub species for land regeneration has produced information on species suitability and drought tolerance for sites with conditions under which it is particularly challenging to establish trees, such as brownfield, mineral workings and other types of previously used land. Further information can be found in the Forest Research Best Practice Guidance Note for Land Regeneration: *Drought-tolerant tree species for land regeneration*.

Key points for watering and irrigation

- Young plants are most at risk, and if there is species variation in sensitivity, consider changing species choice and the timing of planting.
- Watering in the field is unlikely to be feasible at large scale; other options should be considered first.

Adapting infrastructure

Risks reduced					
Windthrow	Wildfire	Pest/disease	Drought	Frost	Flood
●	●	– –	– –	– –	●

Forest and woodland infrastructure includes forest roads and rides, bridges, drainage systems, buildings and other facilities that enable management and access, which may include power and communications networks. Such infrastructure may be costly to install and maintain and therefore represents a substantial investment, with an expected lifetime of up to several decades.

Extensive infrastructure installation is more typical of large high-production planted forests; the requirement is likely to be lower in less intensively managed woodland, for example, in a small, mixed-species wood on a farming property. Nevertheless, the correct design and utility are important, whether it is an extensive road system for a large forest or fencing for a single-hectare restock site. The design and maintenance of roads, drainage systems and buildings should take account of potential changes in requirements as the climate changes. The principal aspects to consider will be the direct influence of the climate on the suitability and durability of the infrastructure, and the indirect effect of adaptations for climate change made to woodland management, which may require different infrastructure. In particular, preparing for increasing storm frequency, which can damage or disrupt utility, road and communications networks, is critical to maintaining safety (see Preparing contingency plans on page 38).

Key points for adapting infrastructure

- Maintaining a road network is critical to provide site access for safety and management. Consideration should be given to the suitability of the design and specification of roads to ensure that they are appropriate both for current use and for potential use if management changes; for example, if there is a change to the frequency of harvesting or thinning operations, wildlife management or to manage diseased trees in the event of an outbreak.
- Where rainfall is projected to become more seasonal and/or more intense, then the infrastructure specifications should be modified to suit and taken account of in the design. For example, increasing the size and number of drainage culverts to reduce the likelihood of forest road washouts and resulting debris flows, or adding more areas for run-off capture to reduce diffuse pollution risks.
- Similarly, if rainfall is reduced, the construction and use of the road may be revised to minimise dry-weather 'blow-away' erosion; for example, by using a more durable road surface material.
- In adapting infrastructure, managers should note the recommendations of the Forestry Commission Technical Note *Reducing greenhouse gas emissions from forest civil engineering*.
- For fire-risk planning in relation to infrastructure management, the Forestry Commission Practice Guide *Building wildfire resilience into forest management planning* provides guidance on the layout of the forest road network, maintenance of verges and provision of water supplies (such as hydrants, fire ponds and fire-fighting dams).

!

The UKFS advises planners and managers to consider projections of changes to rainfall when specifying designs for roads, culverts and drainage systems. Heavier summer rainstorms together with higher winter rainfall may increase the likelihood of flooding.

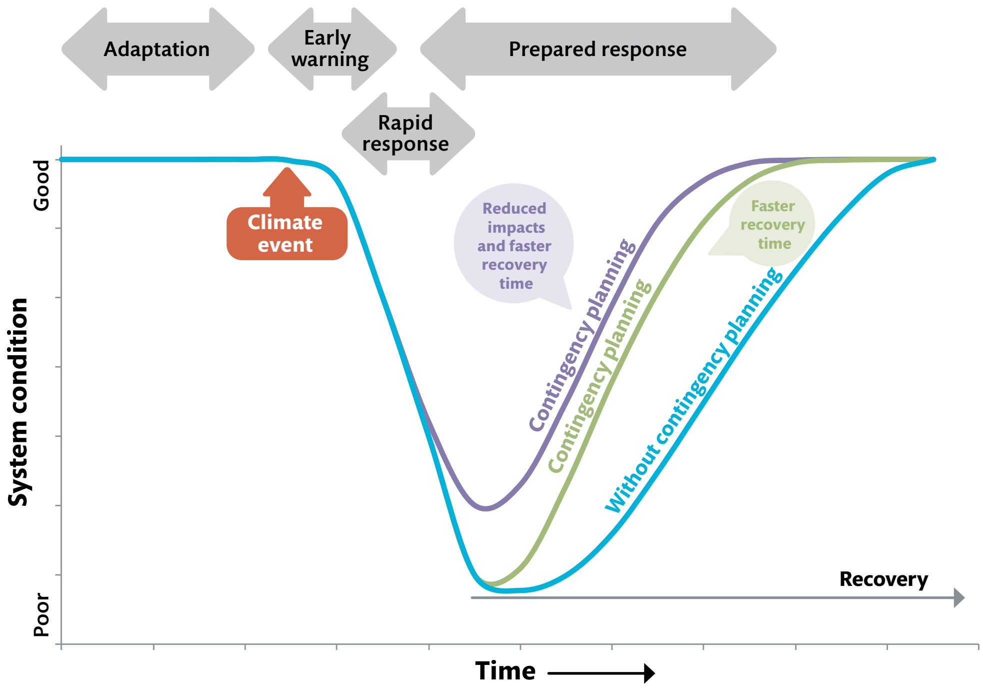
Preparing contingency plans

Contingency plans are pre-prepared plans describing when and how a land manager, business or organisation will deal with actual and potential threats to the forest and environment. Contingency planning for climate change considers both current and future risks related to the changing climate, and both gradual changes and extreme events. These plans aim to reduce risk by enabling a rapid, organised response (Figure 22). Having appropriate contingency plans in place for spillages, pest and disease outbreaks, extreme weather events and fire is a UKFS Requirement for General Forestry Practice. Contingency plans are valuable when the current or future level of potential impact is unacceptably high; therefore, contingency planning is most important for medium- or high-impact risk events.

Contingency plans offer several important benefits. These include having agreed in advance about when and how to respond and having set thresholds for decision-making. Individuals within an organisation know the risks, are prepared in advance for the response and key players have been identified and assigned responsibilities. Where a multi-agency response may be necessary, the appropriate communication channels and chain of command can also be established in advance. Contingency plans are also likely to produce financial savings and a more rapid return to normal business function.

Contingency planning in the forestry sector can minimise impacts to the natural environment and wider social and economic environment and allow forests to continue to meet the desired range of management objectives, allowing a more rapid return to normal function. With advanced planning, secondary impacts can also be managed and interactions with

Figure 22 The benefits of contingency planning. This graph illustrates the impacts of a damaging climate event on a system (e.g. a forest ecosystem or business) and shows change over time with contingency planning (purple and green lines) and without contingency planning (blue line).



other risks considered. For example, the risk of a pest outbreak may increase after a windthrow event (Figure 23), especially if there is a delay in clearing up, or the risk of wildfire increases during spring and summer months after a pest or disease outbreak or following a drought.

Contingency plans can be beneficial at different scales depending on the nature of the risk, type of response required and the type and scale of forest ownership. They can be developed nationally (UK or country), regionally or locally. They may also be developed by a single land manager, at a business level, or across multiple agencies. The basic content of a small-scale contingency plan will overlap with the forest management plan.

Key points for preparing contingency plans

- Contingency plans can reduce the impacts of an incident by increasing response rates and reducing recovery time. This can save money, prevent further damage and take better advantage of potential opportunities (e.g. storing timber after a high wind event may reduce the impact on sale prices, increasing timber value and, by clearing the site, provide opportunities for restocking and diversification).
- They allow managers to plan for risks that are medium or high impact, particularly those which are low likelihood or have a high degree of uncertainty.
- It is important to check if there are national contingency plans in place and to consider how your local site-based plans might fit within a wider framework. For example, national contingency plans have been prepared for the forestry sector for wind damage and pests and diseases in Scotland.
- The plan should explore potential impacts on infrastructure, forest businesses and important conservation habitats.

Figure 23 The risk of a pest outbreak may increase after a windthrow event.

Implementing adaptation measures

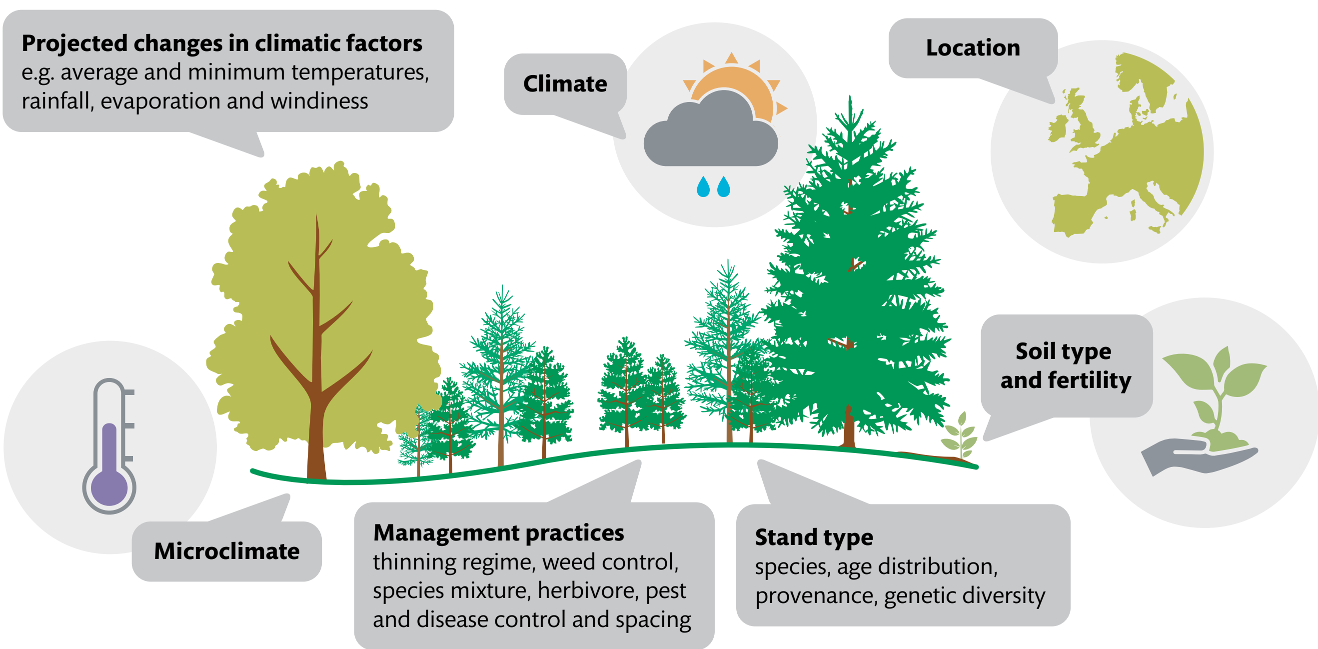
Deciding when, where and how to adapt forest management, over what timescales and how to monitor progress to modify and improve adaptive practice, are complex decisions. Having a good understanding of risks to an area of woodland (page 7) and how suitable the tree species are likely to be in the future climate are particularly important. These will assist in identifying if there are measures that could minimise the risks of decreasing productivity, increased tree mortality and habitat loss, or could increase the benefits from a woodland. Exploring the available adaptation options should also identify those that might not be suitable after a particular time due to climate change or management actions.

All forests should be planned and managed to enhance their resilience and therefore action should be taken to understand and prepare for negative impacts or increased risks to forests. Similarly, where climate change offers opportunities to improve economic, social and environmental benefits from forests then action to bring these improvements forward in time should be considered. Particular triggers for implementing adaptation measures will be where expected future impacts (e.g. reduction in growth rate or loss of tree species) exceed acceptable limits; however, as shown by the Case studies (forestresearch.gov.uk/adapting-forest-management-to-the-changing-climate), the drivers for considering adaptation and implementing the adaptation measures selected can be quite varied. Trees take many years to mature so actions need to be taken before the impacts are observed. Furthermore, as the rate of climate change accelerates, it will be necessary to implement more measures further in advance to increase resilience. Taking early action will also provide important opportunities to learn from experience.

Tree species suitability in relation to climate

For a given site, the suitability of individual tree species for timber production or ecological function, now or at a future date, is influenced by a range of factors (Figure 24).

Figure 24 Factors influencing the suitability of individual tree species for timber production or ecological function now or at a future date.



Understanding the suitability of a species for a site can be informed by experience and the observed growth or performance of existing trees on the site or nearby. However, this may not be an adequate guide to the future growth of trees, particularly as the climate is expected to change considerably over this century.

The combined influence of several of the environmental factors on the suitability of a tree species can be assessed by using the Forest Research tree species suitability tool 'ESC' (Ecological Site Classification), which predicts the suitability of more than 60 different tree species for timber productivity and ecological function, based on the available information on species characteristics and the soils and climate of any location in Great Britain. However, it is important to note that ESC does not take account of the potential impacts of pests and diseases, or the effects of rising atmospheric carbon dioxide concentrations, nor does it take adaptation into account, for example, changing provenance to mitigate declining yield.

The ESC decision-support tool calculates:

- Four climatic factors: accumulated temperature (a measure of site warmth quantified as day degrees above 5°C); moisture deficit (an index of the difference between rainfall and evaporative demand); windiness (by Detailed Aspect Method Scoring, or 'DAMS'); and continentality (reflects the seasonal variability of the climate).

- Two soil quality factors: soil moisture regime and soil nutrient regime.

These factors are used to indicate tree species suitability by assessing predicted yield class (a measure of potential site productivity). Results are displayed for all species assessed and suitability is presented in a 'traffic light' (red, amber, green) chart according to the modelled suitability scores (Table 3 below and Box 1, page 3). For less suitable species, the factors most likely to limit growth are indicated (e.g. soil moisture).

Table 3 Ecological Site Classification (ESC) scores and their description.

ESC score	Description
0.75+	Very suitable
0.5–0.74	Suitable
0.3–0.49	Marginal: species in this category may have significantly reduced growth, a high risk of check or absolute failure
0–0.29	Unsuitable

You can access ESC free of charge online at forestresearch.gov.uk/esc. The tool requires the input of a grid reference (to derive climate information) and, where available, soils information for the site (to estimate fertility and wetness). A soil survey to provide site soil information will improve the accuracy of the analysis. We recommend using ESC to start to assess species suitability. Further information and tutorials are available from the website.

Monitoring and assessing adaptation

Monitoring and documenting what actions are being undertaken and what happens in the woodland as a consequence of those actions, provides important evidence that will help understand how the woodland is adapting to change and what other actions might be helpful. A record of adaptation actions taken is invaluable information.

Given the long timescale of tree growth, clear and comprehensive records provide the key information to assess the success of adaptation measures and the changes happening in the woodland, to share with others implementing adaptation or for subsequent managers. For example, if new planting is being undertaken, you should record what species and provenance, the age and source of material, the planting date, density and techniques of planting and protection provided.

The forest or woodland management plan is the place to record these details, forming a repository of information. It is also useful to record 'beat-up' rates, unusual weather events before or after planting, such as a spring drought, storm damage, and pest and disease outbreaks. We recommend using indicators presented in the Forestry Commission Handbook *Managing native broadleaved woodland*. Alternatively, a simple diary to record adaptation activities can provide a valuable record for future management. A list of possible headings is suggested in Box 2.

Box 2 Useful information to include in a forest adaptation record

1. Location grid reference and stand name/compartments.
2. Brief description of the woodland and soil type (where known).
3. Summary of the primary objectives for the woodland.
4. The main short-term (10 years), medium-term (11–30 years) and long-term risks to the woodland.
5. List of adaptation options considered.
6. List the individuals and groups involved in the decision-making process, when and any techniques used to engage with them.
7. Measures selected for implementation and rationale.
8. Date(s) when adaptation measure(s) were/will be undertaken.
9. Cost of implementation.
10. How the success or failure of measures will be monitored, frequency and by whom.
11. How insights generated could be shared with others looking to adapt their woodland.
12. Other information (e.g. tree supplier, numbers planted, costs, tree provenance, planting date, protection used and beat-up rate).

Note: points 1–4 will be covered by the forest or woodland management plan.

Further reading and useful sources of information

Forestry authority standards and guidance

The UK Forestry Standard and its suite of supporting guidance is available from the Forest Research website at www.forestresearch.gov.uk/ukfs

- The UK Forestry Standard (FCFC001)

- Building wildfire resilience into forest management planning (FCPG022)
- Reducing greenhouse gas emissions from forest civil engineering (FCTN020)
- Protecting the environment during mechanised harvesting operations (FCTN011)
- Extraction route trials on sensitive sites (FCTN010)
- Seed sources for planting native trees and shrubs in Scotland (FCFC151)
- Managing England's woodlands in a climate emergency (Forestry Commission)
- Cultivation of soils for forestry (FCBU119)

Research

Forestry Commission and Forest Research publications are available from the online publications catalogue at www.forestresearch.gov.uk/publications

- Genetic considerations for provenance choice of native trees under climate change in England (FCRP030)
- Encouraging biodiversity at multiple scales in support of resilient woodlands (FCRN033)
- Choice of silver birch planting stock for productive woodlands (FCRN030)
- Converting planted non-native conifer to native woodlands: a review of the benefits, drawbacks and experience in Britain (FCRN024)
- Species preference of small mammals for direct-sown tree and shrub seeds (FCRN013)
- Potential impacts of drought and disease on forestry in Scotland (FCRN004)
- Impacts of climate change on forestry in Scotland - a synopsis of spatial modelling research (FCRN101)
- Climate change: impacts and adaptation in England's woodlands (FCRN201)
- The role of forest genetic resources in helping British forests respond to climate change (FCIN086)
- Choosing provenance in broadleaved trees (FCIN082)
- Selecting the right provenance of oak for planting in Britain (FCIN077)
- Monitoring the transformation of even-aged stands to continuous cover management (FCIN045)

Other publications

- Best practice guidance for land regeneration (Forest Research) – Drought-tolerant tree species for land regeneration (Note 20)
- Climate change adaptation manual (Natural England)
- Climate change impact report cards (LWEC/NERC)
- Combating climate change – a role for UK forests (The Read Report) (TSO, Edinburgh)

- The role of contingency planning in climate change adaptation for the forestry sector in Scotland (ClimateXChange/Forest Research)

Websites

UK forestry authorities

- England: Forestry Commission – www.gov.uk/forestrycommission
- Scotland: Scottish Forestry – www.forestry.gov.scot
- Wales: Natural Resources Wales – www.naturalresourceswales.gov.uk
- Northern Ireland: Forest Service – www.daera-ni.gov.uk/forestry

National adaptation programmes

- England: Defra (Department for Environment, Food and Rural Affairs) – www.gov.uk/government/publications/climate-change-second-national-adaptation-programme-2018-to-2023
- Scotland: Scottish Government – www.gov.scot/publications/climate-ready-scotland-second-scottish-climate-change-adaptation-programme-2019-2024
- Wales: Welsh Government – gov.wales/prosperity-all-climate-conscious-wales
- Northern Ireland: Department of Agriculture, Environment and Rural Affairs – www.daera-ni.gov.uk/articles/northern-ireland-climate-change-adaptation-programme

Statutory nature conservation agencies

- Natural England – www.naturalengland.org.uk
- NatureScot – www.nature.scot
- Natural Resources Wales – www.naturalresourceswales.gov.uk
- Northern Ireland Environment Agency – www.daera-ni.gov.uk/northern-ireland-environment-agency

Information and advice on the management of threats to woodland, including deer, squirrels and invasive non-natives, is available from gov.uk/guidance/manage-threats-to-woodland-destructive-animals-invasive-species#other-invasive-species

Other useful websites

- Forest Research – www.forestresearch.gov.uk
- About Drought – https://aboutdrought.info
- Climate Change Committee (UK action on climate change) – www.theccc.org.uk
- GB Non-Native Species Secretariat website – www.nonnativespecies.org
- Independent Assessment of UK Climate Risk (CCRA3) – www.ukclimaterisk.org
- Observatree – www.observatree.org.uk
- Plant Healthy certification scheme – https://planthealthy.org.uk/
- Royal Forestry Society (climate change and forest resilience) – https://rfs.org.uk
- Scottish Forestry (woodland grazing toolbox) – https://forestry.gov.scot
- Silvifuture network – www.silvifuture.org.uk
- TreeCheck – www.treecheck.net
- UK climate projections – http://ukclimateprojections.metoffice.gov.uk
- UK National Ecosystem Assessment – unep-wcmc.org

Appendix 1: Support for adaptation

Further information and advice on forest and woodland management to support national adaptation programmes in England, Scotland and Wales are available.

In England

The GOV.UK website contains guidance on planning, establishing and managing woodlands that are resilient to the changing climate so that they continue to make their important contribution to a future low carbon economy:

www.gov.uk/government/collections/climate-change-and-resilient-woodlands

In Scotland

Resources to help forest and woodland owners and managers implement the UK Forestry Standard requirements on resilience are available on the Scottish Forestry website:

forestry.gov.scot/forests-environment/resilient-forests

In Wales

The NRW (Natural Resources Wales) website contains a range of guidance for woodland managers on planning for the future at:

naturalresourceswales.gov.uk/guidance-and-advice/business-sectors/forestry/woodland-management/guidance-for-woodland-owners-and-managers

Topics include guidance on making woodlands more resilient; tree species choice; silvicultural systems and genetic diversity.

Appendix 2: Case studies of adaptation practice

Case studies of adaptive practice to support this Practice Guide are available to view and download on the Forest Research website at:

forestresearch.gov.uk/adapting-forest-management-to-the-changing-climate

These have been selected to demonstrate examples of forests and woodlands where owners and managers have started to adapt to climate change (Figure A2.1). Where possible these follow the adaptation framework described on page 4 in Figure 2 of this Guide. The case studies range in size from small woodlands of three hectares to large forests of nearly 70 000 hectares. Each study shows how various risks and opportunities have been assessed in order to work out how best to adapt to the changing climate and includes information about tools or sources of information that informed decision-making. The impacts of climate change are being felt first in woodlands in the southeast of England and, although there are examples of adaptation across the UK, this higher urgency in the southeast is reflected in the locations of the case studies presented.

Many of the forests can be visited if you would like to view adaptation on the ground. More case studies will be added in the future; please check online for the latest examples.

Figure A2.1 The locations of the various case studies of adaptive practice that are currently available to support this Practice Guide.

1. Climate-ready forestry at Queen Elizabeth Forest Park
2. Managing a woodland with acute oak decline: Bell Coppice
3. Jeskyns mixed broadleaf climate adaptation demonstration
4. Bicentenary project: planning 200 years ahead in Gipps Wood
5. Demonstrating climate change adaptation in Alice Holt Forest
6. Planning to reduce the future risk of fire in Swinley Forest
7. Transformation to continuous cover forestry at Clocaenog Forest
8. Land management planning in West Sutherland
9. Sustainable forest management at Kinveachy Caledonian pinewoods

!

To share your experience and comments with us and others, email climatechange@forestresearch.gov.uk

Glossary

Adaptation Initiatives and measures to reduce the vulnerability of natural and human systems against actual or expected climate change effects. In the context of forestry, it means reducing the vulnerability of forests – as well as using forests to reduce the vulnerability of society to climate change.

Adaptive management A systematic process for continually improving management policies and practices by learning from the outcomes of operational programmes.

Ancient woodland Woodland that has been in continuous existence since before AD 1600 in England, Wales and Northern Ireland, and before AD 1750 in Scotland. The term, ancient woodland site, refers to the site of an ancient woodland irrespective of its current tree cover. Where the native tree cover has been felled and replaced by planting of tree species not native to the site it is referred to as a plantation on an ancient woodland site (PAWS).

Anticipatory (or proactive) adaptation Adaptation that takes place before impacts of climate change are observed.

Assisted migration The sourcing of seed (or other sources of forest reproductive material) from populations experiencing climate regimes predicted for planting sites into the future and deploying them in various mixtures with other non-local or local sources of seed.

Beating-up (or beat-up) Adding plants a year or two after initial planting to replace failures.

Biosecurity A set of measures designed to prevent the spread of harmful organisms or diseases.

Brash The residue of branches, leaves and tops of trees, sometimes called 'lop and top', usually left on site following harvesting.

Carbon sequestration (of carbon or carbon dioxide) The removal from the atmosphere of carbon or carbon dioxide through biological or physical processes and their retention in living biomass or wood products.

Clearfelling Cutting down of an area of woodland (if it is within a larger area of woodland it is typically a felling greater than 0.25 hectares). Sometimes a scatter or small clumps of trees may be left standing within the felled area.

Climate projection A climate projection is the simulated response of the climate system to a scenario of future emissions or concentration of greenhouse gases and aerosols, generally derived using climate models. Climate projections depend on the emission/concentration/radiative-forcing scenario used, which is in turn based on assumptions concerning, for example, future socioeconomic and technological developments that may or may not be realised.

Climate scenario A plausible and often simplified representation of the future climate, based on an internally consistent set of climatological relationships.

Connectivity The degree to which the landscape facilitates or impedes movement among resource patches.

Contingency plan A plan of action to address potential threats to the forest such as pollution, pest attack or wind damage.

Continuous cover forestry An approach to forest management whereby the forest canopy is maintained at one or more levels without clearfelling.

Culvert A structure, usually a large pipe, that allows water to flow under a road.

DAMS (Detailed Aspect Method of Scoring) A system for scoring windiness derived from tatter flags and using representation of location and terrain to calculate a score (see forestresearch.gov.uk/forestgales for more information).

Deadwood All types of wood that are dead including whole or wind-snapped standing trees, fallen branch wood and stumps, decaying wood habitats on living trees such as rot holes, dead limbs, decay columns in trunks and limbs, and wood below the ground as roots or stumps.

Design plan The part of a forest management plan that predominantly addresses landscape and visual aspects.

Ecosystem services The benefits people obtain from ecosystems. These include provisioning services such as food and water; regulating services such as regulation of floods, drought, land degradation and disease; supporting services such as soil formation and nutrient cycling; and cultural services such as recreational, spiritual and other non-material benefits.

Emerging species Tree species that exhibit potential for more frequent or wider use.

Emissions scenarios A plausible representation of the future development of emissions of substances that affect the earth's radiation balance (e.g. greenhouse gases, aerosols), based on assumptions of demographic and socioeconomic development as well as technological change.

Forest infrastructure Structure and facilities that enable the practice of forestry such as roads, tracks, stacking and landing areas, buildings, ditches, bridges and communication facilities.

Forest management plan (woodland management plan) A plan that states the objectives of management together with details of forestry proposals over the next five years and outlines intentions over a minimum total period of 10 years.

Forest plans allow managers to communicate proposals and demonstrate that relevant elements of sustainable forest management have been addressed, and can be used to authorise thinning, felling and other management operations.

Invasive species Animal or plant species that spread rapidly, to the exclusion of other species. Many invasive species are not native or locally native.

Maladaptation Actions that may lead to increased risk of adverse climate-related outcomes, increased vulnerability to climate change, or diminished welfare, now or in the future.

Mitigation (of climate change) A human intervention to reduce the sources or enhance the sinks of greenhouse gases. In this context, establishing and managing forests and their products to enhance their potential as a 'sink' of greenhouse gases, or to reduce fossil fuel use, is a mitigation activity.

Native species Species that have arrived and inhabited an area naturally, without deliberate assistance by humans. For trees and shrubs in the UK, that is usually taken to mean those present after post-glacial recolonisation and before historical times. Some species are only native in particular regions of the country and are introduced elsewhere. Differences in characteristics and adaptation to conditions occur more locally – hence 'locally native'.

Natural regeneration Plants growing on a site as a result of natural seedfall or suckering, which can be from existing or recent tree cover, or be from the dispersal of seeds from more distant seed sources (the latter is sometimes referred to as natural colonisation). The term is also used to describe silvicultural practices used to encourage natural seeding and establishment.

National Vegetation Classification (NVC) A system of classifying natural habitat types in the UK according to the vegetation they contain. The NVC provides a systematic and comprehensive account of the vegetation types of the country, covering all natural, semi-natural and major artificial habitats in the UK.

Percentile A measure used in statistics indicating the value below which a given percentage of observations in a group of observations falls. For example, the 20th percentile is the value below which 20% of the observations may be found. Similarly, 80% of the observations are found above the 20th percentile.

Phenology The study of natural phenomena in biological systems that recur periodically (e.g. development stages, migration) and their relation to climate and seasonal changes.

Priority habitat or species Habitats and species that have been listed as priorities for conservation action in biodiversity strategies.

Projection Forecast of a future situation based on a study of present trends.

Protected habitat or species Habitats or species protected by EU Directives and transposed into UK law by the Habitats Regulations. These provide a range of protection and conservation measures including the Natura 2000 network of protected sites and schedules of European Protected Species. In addition, a range of UK and country wildlife, countryside and conservation legislation provides protection for special sites and listed species.

Provenance Location of trees from which seeds or cuttings are collected. Designation of Regions of Provenance under the Forest Reproductive Material Regulations is used to help nurseries and growers select suitable material. The term should not be confused with 'origin', which is the original natural genetic source.

Resilience The ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity for self-organisation, and the capacity to adapt to stress and change.

Restocking Replacing felled areas by sowing seed, planting, or allowing or facilitating natural regeneration.

Risk The potential for consequences where something of value is at stake and where the outcome is uncertain, recognising the diversity of values. Risk is often represented as the probability of occurrence of hazardous events or trends multiplied by the impacts if these events or trends occur. Risk results from the interaction of vulnerability, exposure and hazard.

Risk assessment The qualitative and/or quantitative scientific estimation of risks.

Semi-natural woodland Woodland composed of mainly locally native trees and shrubs that derive from natural seedfall or coppice rather than from planting. However, the definition varies according to the local circumstances in England, Scotland, Wales and Northern Ireland.

Structural diversity The degree of physical variation in the elements of a forest, particularly the spatial distribution of trees, and vertical distribution of the canopy and other layers of vegetation.

Understorey The vegetative layer and especially the trees and shrubs between the forest canopy and the ground cover.

Windthrow (or windblow) Uprooting or snapping of trees by the wind.

Yield class An index used in the UK of the potential productivity of even-aged stands of trees. It is based on the maximum mean annual increment of cumulative timber volume achieved by a given tree species growing on a given site and managed according to a standard management prescription.

UKFSPG026/FR(ECD)/JTCP-0.5K/MAY22

Our climate is changing rapidly, with milder, wetter winters, warmer summers, longer growing seasons and more frequent extreme conditions, including drought periods and heavy rainfall events. The projected rate of climate change is unprecedented and therefore action is essential now to improve the resilience of forests and woodlands, and to protect the benefits that they provide. This Practice Guide provides advice to forest and woodland owners, managers, planners and policymakers on how to adapt management and plan for the changing climate by providing an adaptation framework that takes the reader through the process of choosing and implementing appropriate adaptation measures. It brings together the latest insights from research and practice, supplemented by case studies to show how adaptation measures are being applied. This Guide supports the UK Forestry Standard and its Guidelines on Climate Change, which are the primary source of information on good practice requirements.

£12.00

www.forestresearch.gov.uk/ukfs