COMBATING CLIMATE CHANGE

A ROLE FOR UK FORESTS

An assessment of the potential of the UK's trees and woodlands to mitigate and adapt to climate change

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First published in 2009 by The Stationery Office Limited, 26 Rutland Square, Edinburgh EH1 2BW.

ISBN: 978-0-11-497351-3

Recommended citation: The Read Report, or in full as below.

Read, D.J., Freer-Smith, P.H., Morison, J.I.L., Hanley, N., West, C.C. and Snowdon, P. (eds). 2009. *Combating climate change – a role for UK forests. An assessment of the potential of the UK's trees and woodlands to mitigate and adapt to climate change.* The Stationery Office, Edinburgh.

Foreword

In a world confronted with the possibility that human-induced warming of the climate will bring catastrophic consequences, it is incumbent upon each nation to maximise its own contribution to ameliorative activities. These actions can be of two kinds. The first involves the production of national targets for reducing emissions of carbon dioxide and the other greenhouse gases that drive the warming process, while the second seeks to increase the rates at which we contribute to the removal of these potentially damaging components from the atmosphere.

In this assessment we provide a scientific analysis of the potential for actions of this second type. We examine the abilities of the UK's trees, forests and forest products to absorb and retain the greenhouse gas carbon dioxide. What emerges is an urgent need to increase the extent of forest cover in the UK so that we can make an appropriate contribution to the global requirement for mitigation of greenhouse gas emissions.

By intercepting and trapping solar energy and carbon dioxide, tree canopies form effective sinks in which the principal agent of the warming process is removed from the atmosphere and sequestered in solid form as wood. The effectiveness of trees in these light- and carbon-scavenging processes is revealed both by the extent of shading and temperature amelioration observed at the forest floor, and by the rapid growth rates that they achieve, often on land too marginal for agricultural practice. These capabilities have long been recognised and exploited in Britain, particularly in the production of timber for strategic and economic purposes. Herein lies a problem of a historical nature that is not peculiar to our islands but which is particularly disadvantageous to those of us who now recognise the potential of trees to act as carbon 'sinks' in the British context. This is that, while our once bountiful indigenous resource was removed for the development of agriculture and effectively exploited for fuel and building materials, the UK has been far less effective in replanting forests. Essentially, harvesting along with long periods of little or no reforestation or afforestation have had the consequence that, whereas our islands before human occupation had supported up to 80% forest cover, this figure had fallen to around 5% by the mid-1920s. Even today, with UK forest cover at around 12% of land area, we are one of the least well forested countries in Europe. While importation of timber and pulp has provided some solution to the demands of constructional and paper-producing industries of the UK, the problem confronting those who contemplate the use of home-grown trees and forests as frontline defences against climate change remains a challenging one! Here, we address this problem. We do so, not with a view to finding some 'quick fix' for an emerging short-term climate challenge but with the intention to identify an ongoing and progressively increasing contribution of UK forests to the mitigation of what will be a lasting legacy of excessive fossil fuel exploitation.

We ask and answer questions concerning the present and predicted abilities of UK forests to act as carbon sinks. We also examine how the substitution of wood for fossil fuels and its use in place of materials which require large greenhouse gas emission in their manufacture, can optimise the benefits of the UK forest resource. Ongoing climate change is impacting our woodlands now, influencing their ability to provide environmental, biodiversity, economic and social benefits. Some adaptation will occur naturally, but UK woodlands are managed ecosystems and forest management provides an opportunity to achieve adaptation in a time frame that will limit catastrophic impacts. Inevitably, planting for the future involves some risks and uncertainties but these are no justification for inaction. We are in a position to make maximum likelihood assessments of climate scenarios in mid century and are already armed with sufficient ecological knowledge to enable informed choices concerning the abilities of current as well as new species and provenances to grow well and meet our forestry objectives in the environments that will confront the next generation.

Analysis of the basic science confirms both that climate warming is occurring and that trees are already responding in their growth patterns to these changes. In view of the fact that emissions of greenhouse gases and the associated warming are predicted to increase further, we need to optimise the effectiveness of trees as natural agents for the capture of carbon from the atmosphere. Clearly such considerations cannot be made in isolation. Other pressures upon human populations and the environment, not least those surrounding the adequacy of food supply, will be increasingly to the fore. In such contexts, foresters will need, where possible, to avoid competition with agriculture by exploiting the abilities of trees to grow well, and without the need for fertiliser application, on land that is not suitable for food crops. One legacy of our history of deforestation is that land considered marginal or unsuitable for agriculture is abundantly available in the UK. If, in our quest to enhance carbon capture by trees, we are to exploit these resources, we must do so in a way that minimises carbon release from the soil and other adverse consequences. Changes of forest practice and of wood utilisation to accommodate these requirements are also considered in this text.

While fully recognising that under any foreseeable circumstance economic, social and local environmental factors will act to constrain our abilities to use trees and forests as agents for mitigation of climate change, our intention here is to expose the considerable potential of forestry to contribute to the emerging environmental challenges. Our analysis has been principally of UK forests, their current and potential benefits, however much of the science reviewed here has wider implications and the UK has considerable expertise in woodland creation and sustainable forest management. Climate change is a global problem and there are important international dimensions. We owe it to succeeding generations both here in the UK and elsewhere in the world to investigate, evaluate and employ every possible means to ameliorate the environmental impacts that are arising from the comfortable but profligate styles of life that many in the developed world are fortunate to enjoy.

Sir David Read FRS

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Acknowledgements

It is a pleasure to acknowledge the support and encouragement of Tim Rollinson (Director General, Forestry Commission) who commissioned this report. Special thanks are due to Elaine Dick, our Production Editor, for her constructive inputs, as well as for the forbearance and fortitude that she showed throughout the production process, and to Peter Freer-Smith and Pat Snowdon for meticulously attending to editorial and administrative matters. We would also like to thank our two international reviewers William Hyde and Denis Loustau.

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EXECUTIVE SUMMARY

Key Findings

UK forests and trees have the potential to play an important role in the nation's response to the challenges of the changing climate. Substantial responses from the UK forestry sector will contribute both to mitigation by abatement of greenhouse gas (GHG) emissions and to adaptation, so ensuring that the multiple benefits of sustainable forestry continue to be provided in the UK.

A clear need for more woodlands

Forests remove CO_2 from the atmosphere through photosynthesis and, globally, could provide abatement equivalent to about 25% of current CO_2 emissions from fossil fuels by 2030, through a combination of reduced deforestation, forest management and afforestation. Analysis of woodland planting scenarios for the UK indicate that forestry could make a significant contribution to meeting the UK's challenging emissions reduction targets. Woodlands planted since 1990, coupled to an enhanced woodland creation programme of 23 200 ha per year (14 840 ha additional to the 8360 ha per year assumed in business as usual projections) over the next 40 years, could, by the 2050s, be delivering, on an annual basis, emissions abatement equivalent to 10% of total GHG emissions at that time. Such a programme would represent a 4% change in land cover and would bring UK forest area to 16% which would still be well below the European average.

Woodland creation provides highly cost-effective and achievable abatement of GHG emissions when compared with potential abatement options across other sectors. The Committee on Climate Change considered that abatement costing less than £100 per tonne of CO_2 was cost-effective. All the woodland creation options evaluated here met this criterion including a range of broadleaved woodlands. The two most cost-effective options were conifer plantations and rapidly growing energy crops, but mixed woodlands managed for multiple objectives can also deliver abatement at less than £25 per tonne CO_2.

An enhanced woodland creation programme would help to reverse the decline in the rate of atmospheric CO_2 uptake by forests that is reported in the UK's Greenhouse Gas Inventory. From a maximum of 16 $MtCO_2$ per year in 2004, the strength of the 'forest carbon sink' is projected to fall to 4.6 $MtCO_2$ per year by 2020, largely because of the age structure of UK forests and the maturation and harvesting of the woodlands created as a result of the afforestation programmes of the 1950s to 1980s. The decline in planting rates since the 1980s also contributes to this serious projected decline in the sink strength of UK forests.

The new woodlands would also deliver a range of co-benefits but would need to respect a range of other land-use objectives including biodiversity, food security, landscape and water supply.

An asset to be managed wisely

Existing UK forests, including soils, are both a large store of carbon (estimated at around 790 MtC) and a system removing CO_2 from the atmosphere (about 15 $MtCO_2$ per year in 2007). Sustainable forest management can maintain the carbon store of a forest at a constant level while the trees continue to remove CO_2 from the atmosphere and transfer a proportion of the carbon into long-term storage in forest products. The total carbon stored in the forest and its associated 'wood chain' therefore increases over time under appropriate management systems.

Impacts of climate change are beginning to become apparent in the UK's woodlands, including effects on productivity, tree condition, woodland soil function, woodland fauna and flora and forest hydrology.

There is increasing concern over the number of outbreaks of novel pests and diseases in forestry and arboriculture. Forest pests and diseases could compromise the ability of woodlands to adapt and contribute to meeting the challenge of climate change.

The regulatory framework and sustainability standards for UK forestry will need to be maintained and, in some cases, adapted to address climate change. A similar approach should be put in place for the management of urban trees. This will ensure that trees continue to deliver a wide range of ecosystem services.

The status quo is not an option

Since tree crops take many years to mature, the planning horizons for forestry are inherently long. Actions taken now may only prove their worth in 50–100 years time and must be appropriate for both the current and future climates. A move towards planned rather than reactive adaptation in woodland creation and management is therefore preferable.

The creation of new woodlands and the restocking programmes of existing forests present major opportunities for adapting forests to future climate change. Changes to the selection of species and provenances for particular sites using the current range of species are required now. These choices can be accommodated using the range of species currently in use. Over longer timeframes, and if greenhouse gas emissions do not decline, we will need to consider the introduction of new species, including those from continental Europe. However, further research is urgently needed to establish which species will be best suited to the changed environmental conditions. The preference for use of native tree species and local provenances under all circumstances will need to be reconsidered.

The changing climate raises difficult questions for conservation of woodland biodiversity. Current descriptions of native woodland communities based on species composition are unlikely to remain valid because some native members of the flora and fauna may struggle to survive.

Harvesting and use of wood increases forestry's mitigation potential

Harvesting of trees leads to transfers of their carbon into wood products where it is stored, often over long periods. These can be used to substitute for those materials the production of which involves high emissions of GHG. Wood products can also be used directly as sources of energy to replace fossil fuels.

Forests achieve their considerable productivities largely in the absence of nitrogen (N) fertilisation, thus avoiding the high fossil fuel costs of N fertiliser production, direct losses of the greenhouse gas nitrous oxide (N_2O) and the risk of pollutant-N loss to the environment as nitrate in water catchments.

Within the next five years sustainably-produced wood fuel has the potential to save the equivalent of approximately 7 $MtCO_2$ emissions per year by replacing fossil fuels in the UK. This contribution could be increased further as bioenergy, including energy derived from woody biomass, makes an increasing contribution to UK targets for renewable heat, power and liquid fuels. The use of biomass for heating provides one of the most cost-effective and environmentally acceptable ways of decreasing UK GHG emissions.

The estimated total quantity of carbon stored in wood-based construction products in the UK housing stock in 2009 is 19 Mt (equivalent to 70 $MtCO_2e$). If the market for wood construction products continues to grow at its current rate over the next 10 years there is the potential to store an estimated additional 10 Mt of carbon (equivalent to 36.7 $MtCO_2e$) in the UK's new and refurbished homes by 2019.

Part of the current failure to accept wood products for use in construction arises from conservatism in the construction industry. Outmoded attitudes need to be robustly challenged by drawing on the evidence and promoting the technical properties of wood.

Trees help people adapt

Trees have an important role in helping society to adapt to climate change, particularly in the urban environment, through providing shelter, cooling, shade and runoff control. Tree and woodland planting should be targeted to: (a) places where people live, especially the most vulnerable members of society, and (b) places where people gather (such as town and local centres) which currently have low tree cover.

Forestry practitioners should engage with the public to contribute to societal understanding and responses to climate change. The changes required will challenge both policy makers and managers to adopt a more flexible approach in response to the emerging body of evidence.

Policy incentives need to be re-designed so that adequate reward is given to the provision of the non-market benefits of forests, especially those relating to the climate change mitigation and adaptation functions of forests.

We conclude that further scientific and socio-economic analysis is required to enable the UK to achieve the full adaptation and mitigation potential of forestry that is identified in this first national assessment. Clear, robust, research programmes will be needed to underpin the changes of forestry policy and practice which are required to meet the new and challenging circumstances.

Forests are a multiple-purpose resource which make up almost a third of the Earth's land surface. Through their photosynthetic and respiratory activities they play a critical role in the global carbon cycle. While there have been numerous global- and continental-scale determinations of the contributions of forests to the planetary carbon cycle, few have considered these issues in depth at the national scale.

Here we present a synthesis of a scientifically-based analysis of the potential of UK forests and trees to play a role in the nation's response to the challenges of the changing climate.

To date the primary scientific input to global climate change negotiations is the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) published in 2007, and a summary of more recent developments was published in 2009. Chapter 9 of the Working Group 3 report on mitigation of the Fourth Assessment concluded that forestry could make a very significant contribution to a low-cost global mitigation portfolio that provided synergies with adaptation and sustainable development. The Stern Review commissioned by the UK Government in 2006 similarly concluded that curbing deforestation was a highly cost-effective way of reducing greenhouse gas (GHG) emissions and that action to preserve forest areas was urgently needed. In response to these two reviews the Forestry Commission (FC) hosted a meeting of all interested parties in London (November 2007) to consider the UK response and produced a climate change action plan. One of the four key actions identified was a national assessment of UK forestry's contribution to mitigating and adapting to climate change, to be published prior to the UNFCCC meeting in Copenhagen in December 2009. To achieve this the present independent expert assessment was commissioned with the remit to provide a better understanding of how UK forestry can adapt to and improve its contribution to mitigation of climate change, with the following specific objectives:

- review and synthesise existing knowledge on the impacts of climate change on UK trees, woodlands and forests;
- provide a baseline of the current potential of different mitigation and adaptation actions;
- identify gaps and weaknesses to help determine research priorities for the next five years.

The UK Government has taken a lead in climate change policy development and, while the current assessment was in progress, set challenging and legally binding targets leading to an emissions reduction of 80% of 1990 GHG emissions by 2050. A contribution to the targeted reductions in atmospheric GHG concentrations can be achieved by increasing the rates at which the gases are removed from the atmosphere through biological uptake.

In its White Paper, the UK Low Carbon Transition Plan (2009), the Government identified woodland creation as a cost-effective way of fighting climate change and recognised the urgency of action to support tree-planting initiatives. This pressure to act is further accentuated by the climate change projections (UKCP 2009) which use model simulations to provide probabilistic estimates of future climate. These indicate that the UK climate will continue to warm substantially through this century; that there will be changes in rainfall patterns and its seasonal distribution; and that considerable regional variations can be expected. These projections are timely since they provide the essential physical background needed to inform those adjustments of forestry policy and practice that will be required both to mitigate the impacts of the projected changes and to tailor adaptation measures to local conditions.

The science reviewed here and the general implications for policy advice which arise from it are thus presented at a critical time in the development of UK policies on woodland creation and of other actions designed to achieve adaptation and mitigation through UK forestry. Our assessment has yielded the overarching and strongly-held conviction that, confronted by climate change, substantial responses are required of the forestry sector. This evaluation of the science shows that the UK forestry sector can contribute significantly both to the abatement of emissions and to ensuring, through effective adaptation, that the multiple benefits of sustainable forest management continue to be provided.

Forests and atmospheric carbon

The largest impact of forests on atmosphere/land surface exchange arises through the net ecosystem exchange of carbon. Woodlands and forests are a net sink of CO_2, i.e. they remove CO_2 from the atmosphere, except during tree harvesting and for a relatively short period thereafter (the duration depending on soil type and other site factors). The strength of this sink (i.e. the rate of removal) has been quantified for general UK forest types (coniferous and broadleaved woodlands) and the impact of some management activities on CO_2 emissions and removal are known. While there are gaps in understanding, sufficient is known for the overall GHG balance to be calculated and for projections to be provided for both the existing UK forest cover and for a range of alternative forest management scenarios.

Measurements made over several years in a coniferous forest in Scotland show average annual removal from the atmosphere of around 24 tonnes of CO_2 per hectare per year ($tCO_2\ ha^{-1}\ yr^{-1}$). Comparable measurements made in an oak forest in southern England indicate that it removes *c.* 15 $tCO_2\ ha^{-1}\ yr^{-1}$ (Chapter 3, Figures 3.3 and 3.6, pages 30 and 32). Analysis shows that the rate at which carbon accumulates in forest stands from one crop of trees ('rotation') to the next rotation is influenced by site (particularly soil type), forest operations and by the extent of soil disturbance at planting and harvest. In considering emissions abatement it is important to note that, while forest carbon stocks will reach upper limits, the total abatement can continue to rise over successive rotations because of carbon storage in wood products and the substitution of wood for fossil fuel. The dynamics of the current and projected UK forest carbon sink are largely determined by historic planting patterns which involved extensive afforestation, mostly in the uplands, through the 1950s to 1980s. The *c.* 1 million hectares of coniferous forest planted in the UK, mainly on marginal land, over this period represents a major resource as both a carbon store and a carbon 'sink'. In contrast to agricultural crops, such forests achieve their considerable productivities largely without the application of nitrogen (N) fertilisers, thus avoiding the high fossil fuel costs of N fertiliser production, direct losses of the greenhouse gas nitrous oxide (N_2O) and the risk of nitrate (NO_3^-) pollution of water resources.

Although the UK's existing forest area has more than doubled over the past 80 years, at around 12% it is amongst the lowest of any country in Europe. Further, annual areas of new planting have declined sharply since 1989 (Chapter 1, Figure 1.1, page 6) and this has important consequences for the potential contribution that UK forests can make to mitigation of climate change. Current estimates show that, largely as a result of the earlier planting activities, the strength of the UK carbon sink increased from 12 $MtCO_2\ yr^{-1}$ in 1990 to a peak of 16 $MtCO_2\ yr^{-1}$ in 2004. In Scotland, where woodland cover is higher than in the rest of the UK and the population density is smaller, the removal of CO_2 by forests currently accounts for around 12% of emissions. However, the situation is very different in England, where the forest carbon sink equates to less than 1% of total GHG emissions.

Because of the age structure created by the planting history in UK forestry, as the harvesting of the forests created in the last century continues, falls in net CO_2 uptake by UK forests are expected even though harvesting is usually followed by restocking. Significantly, the afforestation rates of the post-war years have subsequently been greatly reduced, so the projected CO_2 uptake by UK forests shows a marked decline to as little as 4.6 $MtCO_2\ yr^{-1}$ by 2020 (Chapter 8, Figure 8.1, page 141). Such declines, which are reported as part of the UK's GHG inventory to the UNFCCC, have serious implications for our ability to meet the challenging targets for emission reductions outlined in the Climate Change Act and the UK Low Carbon Transition Plan. The rapid diminution of the carbon sink provides both a challenge and an opportunity for the forestry sector, and by making provision for reversal of this trend it has the potential to increase its total contribution to climate change mitigation.

Baseline and potential for mitigation in UK forests

The total carbon stock in UK forests (including their soils) is approximately 790 MtC and the stock in timber and wood products outside forests is estimated to be a further 80 MtC. Changes to the large forest carbon stocks can be achieved through management practices. More intensive Forest Management Alternatives (FMAs – see Chapter 6, Table 6.3, page 104) have the lowest standing carbon stocks, but by far the highest annual rates of carbon sequestration (uptake). Since these estimates consider only carbon in the forest, they do not include the further potential of wood to provide abatement of GHG emissions by substituting for fossil fuels as well as for materials which cause large GHG emissions in their production.

Models have been developed which simulate the full life cycle of carbon, including that retained in forest products and fossil fuel emissions avoided by the use of forest products. These enable us to provide, for the first time, a comprehensive evaluation of the abatement potential of UK forests. These model calculations demonstrate that a combination of increased new planting and the substitution benefits of wood fuel and wood products for fossil fuel intensive materials, has the potential to deliver significant abatement (i.e. reduction in net GHG emissions). New woodlands can be planted to deliver a range of forestry and other objectives. Different options for planting provide the potential for significant abatement either as sequestration or substitution, particularly over the longer term (Chapter 8, Figure 8.5, page 154). Energy forestry, in contrast to multi-purpose and conifer/mixed forestry, shows a larger contribution to abatement through substitution than through sequestration in the forest stand and soil.

Clearly, the extent to which abatement can be achieved will be directly proportional both to the increases in area over which the new planting takes place and the extent of fossil fuel substitution that can be gained. For example, woodlands planted since 1990, coupled to an enhanced woodland creation programme involving planting 23 200 ha (14 840 ha over and above the business as usual assumption of 8360 ha per year) of forest per year over the next 40 years, could deliver abatement of *c*. 15 $MtCO_2$ by the 2050s, providing the substitution benefits of wood and timber products are taken into account (see Chapter 8, Figure 8.4, page 148). This level of abatement would equate to about 10% of total GHG emissions from the UK if recent emissions reduction commitments were achieved. Such a programme of woodland creation might incorporate energy forestry, conifer forests, farm and native broadleaved woodland and would establish nearly one million hectares of woodland, bringing total forest cover in the UK to approximately 3.8 million hectares. This rate of afforestation would represent both a major change in, and challenge to, the forestry sector. However it would represent only a 4% change in land use and result in UK woodland cover of 16% which would remain well below the European average. If any such changes of land-use practice were to be implemented it would be important to ensure that the regulatory framework and sustainability standards for woodland creation in the UK were maintained.

Much discussion has centred on the potential of changes in approaches to forest management to deliver emissions abatement. Delaying thinning and harvesting operations to increase in-forest carbon stocks do deliver abatement in the short term if sequestration in forest biomass alone is considered. However, when the abatement associated with wood and timber products substituting for fossil fuels is considered in the analysis, the additional carbon retention delivered through storage in forest biomass is rapidly negated by the lost ability to deliver abatement through substitution. Within a period of 40–50 years, total abatement potential is lower for management scenarios that aim to increase in-forest carbon stocks (see Chapter 8, Figures 8.4 and 8.6, pages 148 and 155). There is therefore a risk that measures that focus solely on increasing forest carbon stocks are likely to limit the abatement potential because of lost opportunities for fossil fuel and product substitution. It is also evident (see Figures 8.4 and 8.6) when a range of options are considered, that there is limited scope for changes in forest management, alone, to deliver significant levels of emission abatement, implying that woodland creation should be the initial focus of activity.

While it is evident from such analyses that the forestry sector has the potential to make a significant contribution to emissions reduction commitments, the economic viability of specific options for woodland creation has to be considered. In establishing the capacity for abatement to be delivered by all sectors, the first report of the Committee on Climate Change considered that abatement costing less than £100 per tonne CO_2 was potentially cost-effective. Here, a detailed analysis of new woodland planting scenarios shows that multi-purpose forestry provides highly cost-effective abatement (0 to £26 per tonne of CO_2), and that abatement using energy forestry (short rotation forestry and coppice) would be even more cost-effective. Indeed, in the case of highly-productive stands the value of timber produced can exceed the cost of establishment and management so that no net social costs arise. In the current assessment, the creation of new native broadleaved woodlands managed for biodiversity objectives is estimated to provide carbon abatement at £41 per tonne of CO_2. However this figure is pessimistic, as it does not include an evaluation of the co-benefits that such woodland creation would provide. Nor does this figure take account of GHG emissions or removal under the land use prior to the creation of the new woodland, which in some cases may be large and add further to the overall benefit of woodland creation. The scale of land-use change envisaged here would clearly require an integrated approach involving full consideration of GHG balances and of all the ancillary benefits of woodland creation.

Impacts and adaptation of forests, woodlands and urban trees

Climate change is already having impacts in UK forestry. These include effects on productivity, tree condition, leaf emergence, woodland soil function, woodland fauna and flora, forest hydrology and, probably, also the incidence of insect pest and tree disease outbreaks. However, there is uncertainty over the likely severity and extent of these impacts in the future.

Increased climatic warmth, the lengthening of growing seasons, and rising atmospheric CO_2 concentrations may improve tree growth rates so long as water is not limiting and pest and disease outbreaks do not have significant impacts. There is good experimental evidence that increases of CO_2 concentration can lead to increased growth of trees although considerable variability of response has been observed determined by genotype, tree age, air pollution and nutrient availability. In the UK, there is only limited evidence that any increases in tree growth or overall forest productivity can be attributed to longer, warmer growing seasons and rising atmospheric CO_2 concentrations. Recent studies attribute increased forest productivity across much of continental Europe mainly to changes in forest management and nitrogen availability.

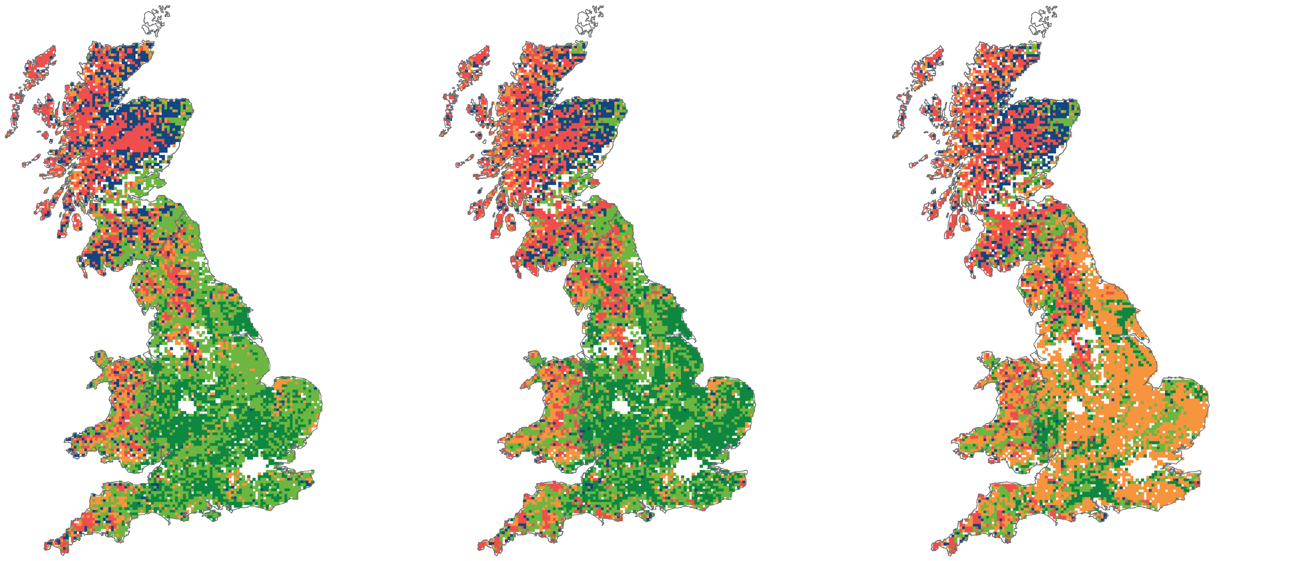
An increased frequency and severity of summer drought is likely to represent the most immediate threat to UK woodlands from the changing climate. There is a very high likelihood that climate change will have serious impacts on drought-sensitive tree species on shallow freely-draining soils. Over the near future (<40 years) the range of species currently considered suitable for use in woodland creation in the UK is likely to remain the same. Exceptions to this general situation are likely to be found in south and east England and more widely in the latter half of the century. The planning of which species and species mixtures to plant on particular sites will be the challenge for forest managers. Over the longer term however (>40 years), especially if high GHG emissions scenarios are taken into account, an extended range of species will have to be considered, Further research is needed to establish which tree species will be most suitable for specific requirements.

Because tree crops take many years to mature, planning horizons in forestry are inherently long. In order to enhance adaptability and resilience of new planting programmes both the current climate and the relatively uncertain projections of the future climate must be taken into account. Models indicate that under a High GHG emissions scenario, significant impacts of climate change on the suitability of species currently used for forestry will become evident by the middle of the century. Under a Low emissions scenario similar impacts will be seen towards the end of the century. Predictions of ‘suitability’ for future UK climate projections have been obtained using a knowledge-based model (Ecological Site Classification) which assesses the influence of temperature, soil moisture, wind risk and soil nutrient availability upon tree performance. This shows that typical conifer stands currently in the ground are likely to reach maturity before serious impacts of climate change are apparent. Importantly, however, the need for adaptation has to be confronted at the time of planting both when restocking and when creating new woodlands. By the end of the century, the climate will have become unsuitable for some native and non-native tree species. The change of climate from suitable to unsuitable for many species will be particularly marked in southern England where even those species which will remain generally suitable for use in the wider UK will struggle on some sites. This is exemplified by the case of oak by the 2050s under a High emissions scenario (see maps opposite). For such species the extent of regeneration from seed and successful establishment may also decline so that they become susceptible to competition from introduced species – by then better suited to the changed climate. The growth of other species may improve, as for example, in the case of Sitka spruce in the west and north west under a Low emissions scenario by the 2050s (see maps opposite). The regional variability of tree responses to climate change that is predicted by current models of perfomance or ecological suitability is crucial because it means that bespoke adaptation strategies are required rather than a generic ‘one size fits all’ approach. For example, of the 28 species assessed using the Ecological Site Classification model, 20 were predicted to increase in suitability in Central Scotland by the 2080s under a High emissions scenario. In contrast, all but two of those species are predicted to show a decline in productivity in southeast England and only one conifer species is predicted to be anything but ‘unsuitable’. Further research is therefore needed to establish which

The ‘suitability’ (defined as productivity relative to maximum productivity achievable by that species under current climatic conditions) for (a) pedunculate oak, and (b) Sitka spruce under Baseline (1961–90, left) and UKCIP02 Low emissions (centre) and High emissions (right) climate change scenarios. The results are based upon Ecological Site Classification (see text for further explanation).

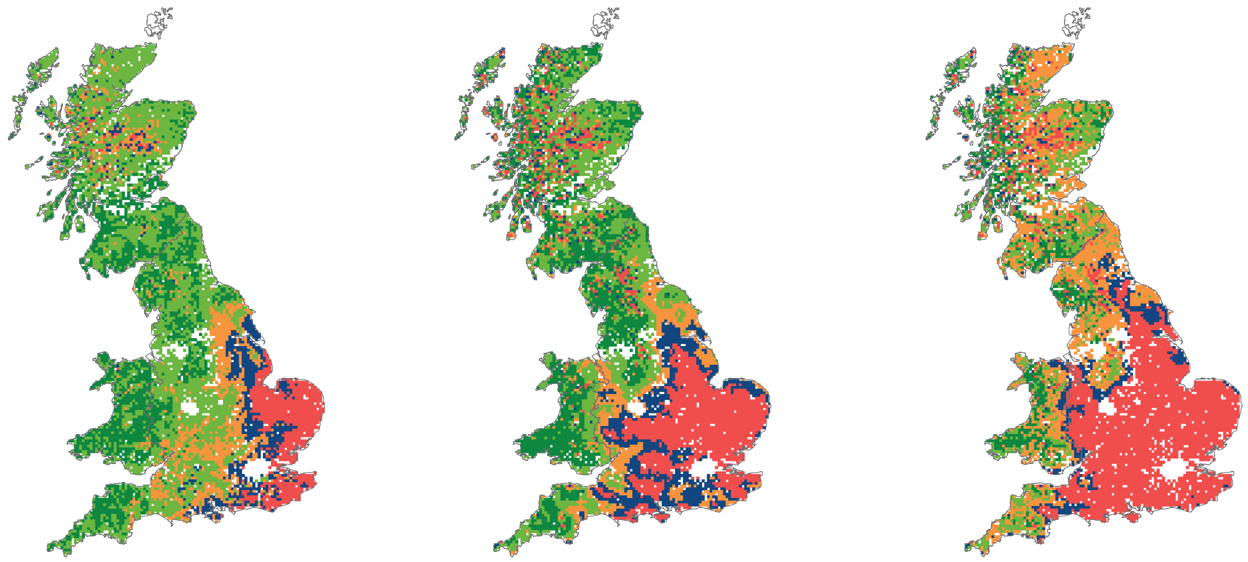
Dark green = very suitable (>70% of current maximum productivity); light green = suitable (50–70% of maximum productivity); orange = marginal (40–50% of maximum productivity); blue = poor (30–40% of max productivity); red = unsuitable (<30% of current maximim productivity).

Pedunculate oak



Baseline | 2050 Low emissions scenario | 2050 High emissions scenario

Sitka spruce



Baseline | 2050 Low emissions scenario | 2050 High emissions scenario

tree species are most suitable for specific requirements and, in particular, to determine which infrequently planted (minor) or untried species are candidates for ‘adaptive planting’ (see Chapter 6, Table 6.5, page 108). The extent of new planting and changes in species choice must, however, be appropriate and sensitive to the potential implications for biodiversity, agriculture, water harvesting, housing and infrastructure development, alongside the other associated costs and benefits.

There are likely to be significant changes to the composition, structure and character of the ground flora and other species of priority for biodiversity and conservation, particularly under High emissions scenarios and over longer timeframes. Current species descriptions of native woodland communities are unlikely to remain valid so the changing climate raises difficult questions for conservation of woodland biodiversity. In replanting, the preference for use of native tree species and local provenances under all circumstances will need to be reconsidered. Diverse semi-natural woodlands are likely to be able to adapt through natural processes, particularly since the majority of native tree species will persist across the UK – albeit with changes in their distribution and growth rate. However for this adaptive potential to be realised, management intervention (i.e. conventional good practice for woodland management) will be necessary in most woodlands to create a diverse structure and promote natural regeneration.

Pests and diseases of forest trees, both those that are already present in the UK and those that may be introduced, currently represent a major threat to woodlands, by themselves, and in interaction with the direct effects of climate change. There have been a number of serious pest and pathogen outbreaks in the UK over the past 15 years and the types of attack which we have seen have the potential to compromise the ability of forests to contribute to addressing climate change. The extent to which increased world trade in plants and forest products and climate change contribute to current threats is uncertain, but there is a need to reduce the future risks and to manage the existing outbreaks. It is essential that appropriate and effective interception and monitoring systems are in place to prevent the introduction of pests and pathogens. We also need early warning of impending threats and an effective response when outbreaks do occur; this requires good interaction between scientists and those responsible for outbreak management.

Trees also have an important role in helping society to adapt to climate change, particularly in the urban environment. Tree and woodland cover in and around urban areas will be increasingly important for managing local temperatures and surface water. Large tree canopies are particularly beneficial. Guidelines should be followed by all concerned parties both to ensure that we continue to maintain and plant trees in urban areas, and to overcome perceived risks including subsidence and windthrow. Where soil water stress is likely to be a problem, planting should focus on more drought-tolerant species. It is crucial that we have a thorough understanding of the current pattern of tree cover in urban areas, to target where we need to maintain and increase cover. There is also an important role for planting woodland along urban river corridors to reduce thermal stress to fish and freshwater life. Tree and woodland planting should be targeted to: (a) places where people live (especially the most vulnerable members of society) which currently have low tree cover, and (b) places where people gather (such as town and local centres) which currently have low tree cover.

Wood fuel and wood products substituting for other materials

By substituting for other materials with greater climate impact, wood products and wood fuel have a significant role to play in reducing carbon emissions in the UK. Forest products should comprise a larger share in the supply of biomass energy and of wood products used in construction. The UK Renewable Energy Strategy considered that renewables could contribute 15% of total energy requirements by 2020, with wood fuel making a significant contribution to the electricity, transport and heat-generating sectors. The UK has a significant biomass resource although estimates of the potential contribution from forestry vary considerably. The Renewable Energy Strategy has identified biomass conversion to heat as a least-cost way to increase the share of renewable heat for which there is a target of 12% by 2020. The deployment of forest resources to achieve these renewable energy targets is now a priority. The annual production of 2 million tonnes of wood fuel from English woodlands is based on the Wood fuel Strategy for England, while the Scottish Forestry Strategy commits to delivering 1 $MtCO_2$ abatement per year through renewable energy production by 2020. Over the next five years wood fuel in the UK has the potential to save up to 7.3 Mt of CO_2 emissions per year by substituting for fossil fuel. If 1 million ha of dedicated energy forests were planted on current agricultural land it would be possible to increase this to the equivalent of 14.6 $MtCO_2$ abatement per year over the next decade. Biomass for heat provides one of the most cost-effective and environmentally acceptable ways of decreasing UK GHG emissions.

Of the UK's current 2.5% by volume of liquid transport fuel obtained from biological sources more than 70% is imported, the sustainability of this supply being largely unregulated. Both the UK and EU will address the issue of sustainability in the near future. The changes likely to be made will involve restriction of feedstocks to those showing at least a 35% improvement in GHG balance relative to fossil fuels. In the UK this could favour the development of the woody biomass energy industry and involve the conversion of woody materials to liquid fuels through biological processes and thermochemical routes such as pyrolysis. To date about half the biomass feedstocks for the UK have come from imports, including approximately 1 million tonnes of biomass for co-firing. The co-firing market in the UK grew by *c.* 150% between 2004 and 2006 and is likely to expand further. This will be driven in part by changes to the Renewable Obligation Certificates (ROCs) which will provide better incentives for home-grown biomass as compared with imported supplies. As a consequence of these measures, bioenergy, including that obtained from wood, is likely to make an increasingly important contribution to UK targets for renewable heat, power and liquid fuels.

Substitution of wood products for materials which release GHG in their manufacture contributes to mitigation of climate change both by storing carbon in our buildings and by reducing fossil fuel consumption. The estimated total quantity of carbon stored in the form of wooden construction products in the UK housing stock in 2009 is 19 Mt. If the wood construction products sector continues to grow as it has in the past ten years there is the potential to store an estimated additional 10 Mt carbon (equivalent to 36.7 $MtCO_2$) in the UK's new and refurbished homes by 2019. This would save a further 20 MtC (73.4 $MtCO_2e$) as a consequence of substitution for more carbon-intensive materials. To date, failure to accept wood products arises in part from conservatism in the construction industry. Outmoded attitudes need to be robustly challenged by drawing on the evidence and promoting the technical properties of wood.

Sustainable development and socio-economic considerations

A complete assessment of the potential for our trees and woodlands to contribute to climate change goals can only be made by examining the social, economic and policy context within which UK forestry operates. The extent to which the potential for additional emissions abatement through tree planting is realised, for example, will be determined in large part by economic forces and society's attitudes rather than by scientific and technical issues alone. Private forest owners will require financial incentives to manage land for carbon sequestration, except where it is a joint venture associated with other types of forestry. Furthermore, trees and woodlands across the UK contribute to a wide range of policy objectives (including, for example, recreation provision and biodiversity protection), and woodlands need to be planned so that these objectives are achieved together with emissions abatement. Clearly, there are demands on land for other purposes – notably food production and urban development – which affect the economic potential for land to be allocated to forestry. Policies and practices in agriculture, planning and development and other urban and rural activities will affect the capacity of woodlands to deliver climate change mitigation and adaptation objectives, whilst the returns available through markets as well as Government support for competing land uses will influence how much new forest planting occurs. Policy incentives need to be re-designed so that adequate reward is given to the provision of non-market benefits, including those relating to the climate change mitigation and adaptation functions of forests. The knowledge built up in the UK and beyond should be used to facilitate more successful mitigation–adaptation interactions in the forestry/land use sectors in the wider context of sustainable development and promotion of rural livelihoods.

Trees and forests have a strong role in the way that people make sense of their environment and of how it is changing. This suggests a particularly significant role for those involved in forest management to engage with the public. By this means they will contribute to a broader understanding of the challenges posed by climate change. The scale and urgency of these challenges are such that they require to be driven at the institutional level, and cannot be left to the actions of individuals.

Grasping the opportunity – next steps to realising forestry's contribution

This Assessment provides the evidence base for a much greater involvement of UK forests and forest products in the fight against climate change. However, provision of the evidence to substantiate the potential contribution of forestry is only the first step towards its realisation. There remain large areas of uncertainty. We have identified research priorities at the end of the chapters in this report that are targeted in particular at these uncertainties, but as important will be the processes of communication of the findings to those in decision-making positions in both the public and private sectors. Awareness at this level will enable the development of policies putting trees, woodlands and forestry at the heart of the UK's response to climate change. The key message of the Stern review was 'Act now or pay later'. In view of the fact that the strength of the carbon sink provided by UK forests is weakening so rapidly, the key message from this Assessment is **'Plant Now and Use Sustainably.'**