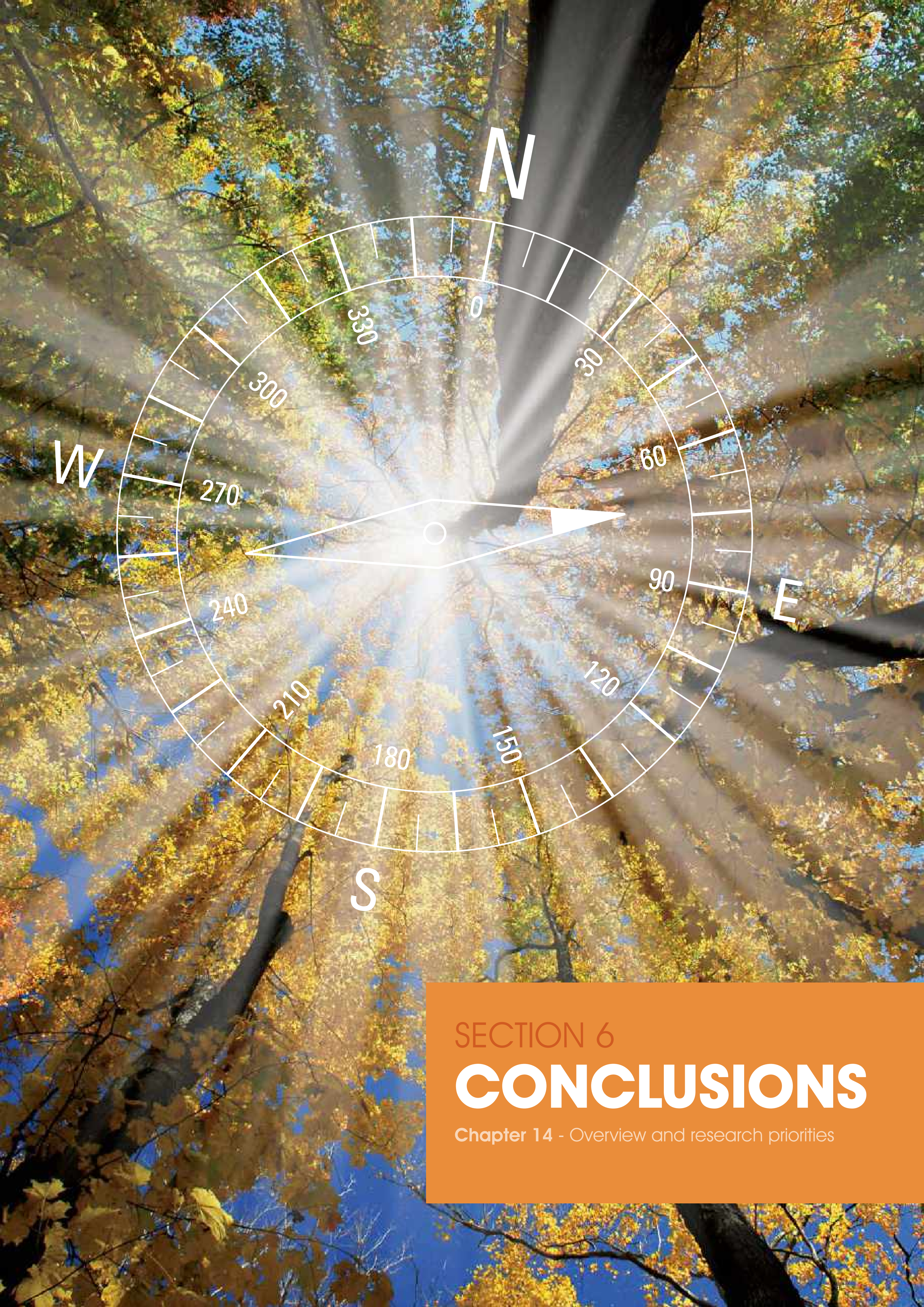

SECTION 6

CONCLUSIONS

Chapter 14 - Overview and research priorities

OVERVIEW AND RESEARCH PRIORITIES

Chapter 14

Sir D. J. Read FRS and P. H. Freer-Smith

This Assessment presents a science-based analysis of the current and potential capabilities of the UK's forests and forest products to contribute to the mitigation of climate change.

It shows unequivocally that: (1) a significant contribution to mitigation could be made by maintaining and increasing the rates at which CO_2 is removed from the atmosphere by the UK's forests – the abatement of emissions; (2) there are other major contributions that forests and trees can make, for example in urban environments, and (3) that there are areas where substantial research is required to assess and reduce impacts and to develop the contribution of UK forestry to the mitigation of, and adaptation to, climate change.

The report follows the IPCC convention of identifying key findings at the start of each Chapter. Authors have also identified research priorities at the end of their respective chapters and these proposals require serious and urgent consideration. Gaps in our understanding are identified and, in some instances, there is a clear requirement for more scientific evidence in order that uncertainties in the projected impacts of climate change can be reduced. The driver in the new research programmes will be the need to enhance the contribution that UK trees and woodlands can make to a low carbon economy. It is the expressed intention of the report to provide the detailed evidence required to achieve sustainable forest management under what will be complex and changing climatic circumstances.

14.1 Overview

The UK faces wetter winters and hotter, drier summers with more drought, heat-waves and flooding. As the future emissions' trajectories cannot be forecast precisely, climate projections are based upon three possible scenarios: high, medium and low emissions. They show considerable regional variation in climate sensitivity. For example, the 2009 UKCP09 projections for a medium-emissions scenario suggest that by the 2050s, average summer temperatures in southern England will rise by 2°C above the 1961–90 average; summer rainfall in the south west will fall by 20%, and winter rainfall in the north west will increase by 15%. Much of our existing woodland, together with the stands being established now, will experience these changes. If global emission control measures do not result in significant decreases in GHG emissions, the UK climate trends will become even more pronounced by the time that new woodlands planted over the next 10–15 years are felled. As a result of the inevitable uncertainties involved in climate predictions, recommendations for improving the contribution of UK forests and urban trees to mitigation of climate change will themselves carry some uncertainty. This in turn necessitates that planting scenarios are subject to risk assessment. As well as research directed towards identification of the major areas of uncertainty, it will be essential to pursue programmes that continuously monitor the effectiveness of actions taken. Sufficient flexibility must be retained in all programmes to enable changes of direction to be achievable where and when they are deemed necessary.

On-going climate change is impacting our woodlands now and will influence their ability to provide environmental, economic and social benefits in the future. Furthermore, 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. When combined with the direct effects of climate change, these threats are likely to become even more serious. Identification of the nature of current and predicted climate change impacts will provide those responsible for the management of our forest resource with the opportunity to adapt their practices in such a way as to limit the severity of impacts. Action is required to change the extent, composition and structure of our woodlands in order to avoid future serious limitations of the goods and services they provide and also to prevent wildlife losses. Indeed, the contribution which the UK's forests and woodlands can make to abatement of GHG emissions cannot be achieved unless effective measures are taken to ensure their adaptation. A number of actions are set out which are designed to achieve such adaptation. These range from the creation of appropriate new woodland to management of some existing woodlands in such a way as to optimise diversity and encourage natural regeneration. In addition it will be necessary to engage in selective restocking of some current stands using species and provenances better suited to the changing climate.

In the urban environment, trees will play an increasingly important role in helping society adapt to the changing climate. It is recognised that all measures taken to provide mitigation and adaptation should be both socially and environmentally acceptable, as well as being cost-effective.

A number of key features of UK forestry are a product of past forest policy. On the positive side, the UK has increased its forest area from a low of *c.* 5% to the current level of nearer 12%. This includes the establishment of about 1 million ha of new fast-growing conifers that currently represent a significant carbon sink. Provided that this important resource is managed with emissions abatement as one of the primary management objectives, it can continue to provide an effective carbon sink. On the negative side the strength of the carbon sink provided by UK forests could decline from a value of about 16 $MtCO_2$ $year^{-1}$ in 2004 to as little as 4.6 $MtCO_2$ $year^{-1}$ by 2020. This is because of ongoing harvesting and the age distribution of the whole UK forest resource, which is a consequence of the decline in afforestation rates since 1989. This decline has serious implications for future UK GHG inventories and in the timescale of the UK's first three carbon budgets (to 2022), can only be modified to a limited extent by increased woodland planting. This is a major concern at a time when the UK Government is seeking to establish a low carbon economy and to take a lead on climate change internationally. However, what emerges from this assessment is that woodland creation over the next 40 years could significantly benefit the UK GHG inventory by 2050. For example, by planting *c.* 23 000 ha per year over the next 40 years the UK could, by the 2050s, be locking up on an annual basis, an amount of carbon equivalent to 10% of our total GHG emissions. Such a programme would restore the UK's annual woodland creation rates to values similar to those seen in the 1970s, 80s and 90s. It would increase the proportion of woodland cover in the UK landscape to 16%. Trees and woodlands across the UK contribute to numerous policy objectives, including the provision of recreation and amenity, the conservation of biodiversity and water management. Clearly, the establishment and management of the new woodlands must be planned in such a way that the required emissions abatement can be achieved without compromising multifunctionality.

Our analysis shows that UK forests and forest soils contain significant amounts of carbon and that the strength of the carbon sink they provide will decline over the next few years unless practice and policy change. Economic analysis suggests that woodland creation is a cost-effective approach for abatement of GHG emissions. This approach is most cost-effective where land opportunity costs are lowest. Currently, UK conifer plantations are providing cost-effective abatement. If the social, economic and environmental co-benefits of woodland creation are also considered, then GHG abatement through woodland creation appears even more cost-effective. The maintenance of a useful carbon sink in existing UK forests and any significant woodland creation programme would require the existing regulatory framework and sustainability standards to be maintained and developed (e.g. the UK Forestry Standard, FC Guidelines on Climate Change, the new Code of Practice for Forest Carbon Projects). Effective standards, guidance and management plans will be essential to ensure that climate change objectives are achieved. These need to be underpinned by strong evidence appropriate to UK conditions. Maximising the capacity of forests to mitigate and adapt to climate change requires actions that are tailored to local and regional conditions. Woodland creation will also require careful spatial planning and targeting in order that it contributes effectively to the full range of forestry objectives.

Success in achieving delivery of the full abatement potential of the UK forestry sector requires an integrated approach involving consideration of not only the carbon stocks in forests but also the roles of wood and timber products directly in substituting for fossil fuels and indirectly as components of the built environment. Forest management has to be effectively co-ordinated with the full timber supply and utilisation chain to ensure that the flow of wood from the forest continues.

Woodlands need to be managed as part of the landscape. Inevitably there are demands on land for other purposes – notably food and energy production and urban and infrastructure development – which affect the economic potential for land to be allocated to forestry. Policies and practices in agriculture, planning development and other urban and rural activities will affect the capacity of woodlands to deliver climate change mitigation and adaptation objectives. 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 the promotion of rural livelihoods.

14.2 Identification of research requirements

The major research requirements which are identified at the end of each chapter are drawn together and summarised below.

The UK has only two forest sites at which CO_2 and energy balances are being recorded continuously; one upland conifer site and one lowland broadleaved woodland. It is important that these sites are maintained and that the measurements should be extended to allow continuous recording of other GHG, particularly CH_4 and N_2O fluxes. Our current understanding of the effects of geographical location, natural events, site disturbance, species, stand age, Yield Class and management operations on GHG exchange is very limited and more research is required. Collaborative experimental programmes, for example, between Defra, CEH, SEPA, University teams and the FC would allow tall towers and aircraft to be used to evaluate emissions and removals of trace gases across landscapes to define major sources and sinks of GHG in relation to forestry, agriculture and other land uses at regional and district scales. This would enable the daily and seasonal sources and sinks of forested and agricultural landscapes to be evaluated at regional scales.

There is evidence, particularly from continental Europe, of increasing forest productivity, perhaps resulting from changes in forest management and increased nitrogen availability. Rising CO_2 concentrations, warmer temperatures, longer growing seasons and in some places increased rainfall could also contribute to the enhancement of forest growth. The absence of a framework for collecting and evaluating detailed information on forest growth and productivity has contributed to the lack of clear evidence of growth trends of British forests. This could delay the implementation of adaptation measures and is a serious disadvantage for those confronted with the need to design new woodland creation programmes. The development of a framework for monitoring and evaluating growth changes on an annual basis is therefore required. Such a framework should be developed as a UK Climate Change Indicator for the forestry sector, and reported on annually. We need to determine whether or not increased forest productivity is occurring in the UK. If increases are detected, the extent to which these will be sustained under projected future climate conditions should be estimated. Conversely, we must recognise that in those areas subject to the deleterious impacts of climate change, the decline and dieback of some of our major species could be envisaged. This would have serious consequences, among which the net release of carbon from forests and forest soils would be the most threatening for the UK GHG balance. The impacts of extreme events on forest ecosystems need to be better understood, particularly the effects of prolonged drought on tree physiology and mortality. Climate projections show that the risks of drought are likely to increase in the UK. Since soil moisture deficits are already serious limiting factors for some tree species in some UK sites, the threats posed by even greater rainfall deficits are significant indeed. A number of other important issues of this type are identified in the chapters of this assessment, many of which require well focused research programmes.

It is important to ensure that the monitoring systems in place are adequate for the new policy and management challenges posed by climate change. The UK's National Forest Inventory is currently under development and will produce a digital map of British woodlands in 2010. In broad terms, the procedures for monitoring and predicting timber production from the UK's forests place us in a good position to plan and review. The National Forest Inventory provides important information on forest cover and woodland type which should help with action on climate change. However, most UK local authorities lack the basic inventories describing the nature and extent of urban trees and woodlands in their districts. This information gap needs to be addressed urgently, with the resulting information on the trees and woods of urban and peri-urban areas being added to the national forest inventory.

We need to continue to improve the forestry-related information that underpins the GHG inventory, and it is essential that there is confidence in the assessment of the potential for forestry to contribute to the abatement of net UK GHG emissions. The conclusions of this review rely heavily on the GHG accounting models used in Chapter 8. While there is sufficient evidence and agreement to justify the recommendations which are made, it is also important to improve these models further, and to underpin them with measurement programmes. The analyses presented in Chapters 7 and 8 show the importance of CO_2 emission abatement achieved through the use of wood in place of fossil fuels and of wood products in substitution for building materials. A comprehensive evaluation of life cycle analyses from a wide range of wood products compared with alternative materials is required to better demonstrate the role of forest management and product displacement in GHG abatement. An operational decision support system needs to be developed to downscale national level assessments of abatement potential through changes in forest management, and to aid the implementation of appropriate abatement measures at regional and local scales.

In the face of the uncertainties inherent in all climate change impact assessments, our modelling capabilities have enabled valuable indications of the likely roles and responses of forests under a range of scenarios. However, we require the development of a hierarchical modelling system combining the practical applicability of knowledge-based decisions support approaches with more theoretical process-based models. Such a system should be designed to represent the effects of changing atmospheric composition and be extended outside the evidence-base of empirical models. Decision support systems are required to integrate understanding and to characterise the structure, function and economic benefits of urban and peri-urban trees and woodlands.

'Climate matching' analysis can identify broad regions that currently experience a climate similar to that projected for the UK in the future. This provides an opportunity to explore the impacts of likely climate change predictions based on model simulations. The approach should be used to explore likely changes in woodland ecosystems, the suitability of tree species for commercial forestry and to inform alterations in forest management that might be required in response to the changing climate. It must, however, be understood that such an approach can only provide broad guidance as complete analogues of future conditions do not exist. We need to improve our understanding of which factors will become limiting for which species at a regional level. Forest trials of potential species that may be suitable for the current and projected British climate are required. This will allow the scope for species translocation, genetic improvement and the use of new provenances and species to be examined. These approaches are important for developing our understanding of how different species will respond to climate change.

Forest planning faces difficult decisions on how to address the many objectives of forestry, in a changing climate. Managers will require more advice and information from the research community in order to make rational decisions when faced with unknown or unfamiliar conditions, and with multiple demands and objectives. We must develop and maintain databases describing how different species (both trees and other woodland species) are predicted to respond to climate change (e.g. using knowledge-based systems, such as Ecological Site Classification, and empirical climate space/envelope modelling). These tools need to be informed by strengthened forest monitoring for early detection of change. This will be essential to allow damage-limiting adaptation measures to be imposed in a timely manner. We need to improve our understanding of how climate change will influence disturbance regimes of wind, fire, pests and pathogens and to develop methodologies to help forest managers identify sites and stands most vulnerable to climate change.

There is evidence of an increased number of pest and pathogen outbreaks both in UK forests and globally over recent years. Whether or not these are related to climate change, such outbreaks pose a serious threat because they could compromise both the growth and resilience of forests. 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. The temperature response of growth should also be determined for a range of tree pests and pathogens to provide the basis for epidemiological modelling of future outbreaks under a changing climate. It is essential that appropriate and effective interception and monitoring systems are in place to prevent the introduction of pests and pathogens. Early identification of impending threats and of new outbreaks can prevent their establishment. Scientific analysis and awareness are the keys to preventing new outbreaks from becoming established. The management of pests and diseases, if they do become established, must also be predicated upon scientific understanding of the outbreaks concerned.

We must improve our quantitative understanding of the impacts of forest management alternatives on the carbon and nutrient budgets and yield of plantations, particularly for new species and management methods. It is known that land preparation, thinning, harvesting and windthrow can have important effects on soil carbon stocks but a better understanding of rates of carbon sequestration and stocks in older forest stands is required because these may need to be retained for landscape and biodiversity reasons. Information of this kind would also allow an improved reporting of forest carbon stocks, including those present in soils, in the National Forest Inventory and would underpin accounting models for forest carbon.

In spite of the considerable potential for using trees as a sustainable source of energy and thereby to contribute to emissions abatement, there are a number of barriers to greater use of woody biomass particularly fast growing species, and these are considered in Chapter 7 of this Assessment. To date there has been a failure to achieve significant planting of woody energy crops in the UK. Estimates provided by the directorate of the Energy Crops Scheme indicate that so far, there has been only limited adoption of short rotation crops (SRC) and short rotation forestry (SRF) practices in the UK. To underpin the wider use of energy crops, more research is required on choice of species, future yields, and on potential diseases and pests. The values of the ecosystem services provided (including the likely carbon benefits) by these schemes also must be evaluated. More extensive implementation of farm-scale trials would fill some of these knowledge gaps. There is considerable potential for the future of new bioscience technologies to improve the photosynthetic gains of bioenergy systems. Other research needs identified include an evaluation of minimal input systems, analysis of energy crops with different carbon qualities (e.g. increased lignin for calorific combustion) and of those with improved resistance to biotic and abiotic stresses. Poplar is currently the model bioenergy tree, and its various genotypes are an important resource from which enhanced traits including improved carbon sequestration and energy production should be obtainable in second generation crops. In addition, new technologies for conversion of biomass to fuel are likely to be developed and, by 2020, gasification and other technologies may be deployed to improve the efficiency with which wood-based energy supplies are processed and delivered.

Initiatives are urgently required to stimulate a step change in the extent to which UK-grown forest products are used in our buildings. Here it must be acknowledged however that the case for increased use of wood is hampered by incomplete and fragmented evidence of the qualities of wood products. In order to highlight the benefits of wood relative to those of other construction materials, GHG balances and energy efficiencies for different construction systems using consistent assessment methods are required. Life cycle analyses of wood products and of biofuel energy systems are essential. The turnover rates of carbon in different wood product pools must be better quantified. It is also important to understand better the behavioural, social and economic barriers to the development of wood energy supply chains and the relative advantages of different wood energy supply systems (chip, pellet, CHP). Furthermore, research on the optimal adaptation of our woodlands needs to take into account the increased requirement for sustainable wood products and woodfuel as the climate change mitigation role of forestry increases.

Further analyses of the cost-effectiveness of forest-based carbon sequestration and emissions abatement programmes are required. These should include comparisons of the marginal costs of abatement through different forestry management options relative to those of other possible alternatives for reducing net emissions (e.g. in agriculture, in housing, transport or industry). Mechanisms enabling the maximisation of the net benefits of managing forests for abatement need to be described. Spatially explicit modelling of carbon and non-market benefits of forests and woodlands remains a research priority. The economic value of ancillary benefits of woodland creation (biodiversity, water quality, recreation, soil protection) need to be incorporated both within cost-effectiveness assessments and in marginal abatement cost curve analyses carried out for the forestry sector. Further investigation is required into the nature of risk and uncertainty in developing forest carbon credit markets. It is not yet clear how this risk can best be managed. The extents of the trade-offs and synergies between managing forests for carbon, relative to other public goals such as recreation, biodiversity conservation, timber supply and water management must be quantified. The benefits of trees and woodlands in helping businesses and people to adapt to the impacts of climate change require to be evaluated.

There is an increasing awareness among the public of the threats to their economic security, lifestyles and wellbeing posed by climate change. It is our intention that this Assessment should highlight the potential for trees and forests to mitigate climate change, so reducing these impacts. It should stimulate greater engagement by individuals, businesses and government in consideration of the future role of trees and forests in the UK landscape. Undoubtedly, some of the measures shown in this study to have significant mitigation potential may not in the first instance receive universal approval. Progress towards broadly acceptable strategies for reducing the impacts of climate change will depend upon cooperative working between organisations, interest groups and individuals, and an understanding of the need to identify widely acceptable solutions. What is very clear is that inaction is no longer an option.

Glossary

Abatement: to decrease GHG emissions including the reduction of net GHG emissions by increasing GHG removal (or uptake) from the atmosphere.

Adaptation: a process by which organisms become better suited to their habitat.

Adaptation to global warming: initiatives and measures to decrease vulnerability of natural and human systems to climate change effects.

Annex B country: one of the 39 industrialised countries under the Kyoto Protocol which has accepted targets for limiting or reducing emissions. These targets are expressed as percentages of each country's GHG emissions as estimated for a base year of 1990 (also known as the assigned amount for the country).

Carbon dioxide equivalent (CO_2e): Over a 100-year time interval the Global Warming Potential (GWP) of methane (CH_4) is 23 times that of CO_2 and nitrous oxide (N_2O) is 296 times that of CO_2. Therefore total GHG amounts are sometimes expressed as CO_2e where more than one GHG is being considered.

Carbon leakages: losses of forest carbon (or increases in GHG emissions) that can occur as an inadvertent result of implementing an emissions reduction or sequestration project. For example, the effectiveness of a project aimed at preventing deforestation in a particular area of forest may be reduced if the causes of the deforestation are simply 'displaced' to a different area of forest. Similarly, the effectiveness of an afforestation project may be reduced if it leads to loss of interest and support for other afforestation projects already in existence.

Carbon offsetting: a way of compensating for GHG emissions by making an equivalent carbon dioxide saving elsewhere. Carbon offsetting involves calculating emissions and then purchasing 'credits' from emission reduction projects see: www.defra.gov.uk/environment/climatechange/uk/carbonoffset/index.htm

Carbon pool or reservoir: a component of the earth system in which a greenhouse gas is stored. Trees, deadwood, debris, litter and soils forming forests are all examples of carbon pools or reservoirs, as are any harvested wood products that retain carbon in wood during their use. Even wood disposed of in landfill could be regarded as a carbon pool.

Carbon sink/source: the carbon balance of a forest is often described as a sink if there is a net transfer of carbon from the atmosphere to one or more of the carbon pools in the forest (resulting in carbon sequestration). When a forest is described as a carbon source there is a net transfer of carbon to the atmosphere.

Clean Development Mechanism (CDM) - The CDM, as part of the Kyoto Protocol, allows industrialised countries with a greenhouse gas reduction commitment (called Annex B countries) to invest in projects that reduce emissions in developing countries as an alternative to more expensive emission reductions in their own countries.

Cost-effectiveness: cost-effectiveness analysis compares the relative expenditure (costs) and outcomes (effects) of two or more courses of action. Regarding carbon sequestration in forestry, cost-effectiveness is expressed in terms of a ratio where the denominator is the carbon stock changes and the numerator is the Net Present Value of the expenditure on the forest measure.

Discounting: is a process used to give different values to costs and benefits occurring at different times. Formally, the Net Present Value (NPV) of a project generating incomes at different times is:

$$NPV = -c + Y1/(1+r) + Y2/(1+r)^2 + ... + YT/(1+r)^T$$

Where *c* is the initial cost, *Y1,.....,YT* - the revenues in real terms at year-zero prices occurring at times *1,.....,T;* and *r* is the discount rate.

The effect of discounting physical carbon is to increase the costs of creating carbon offset credits because discounting effectively results in 'less carbon' attributable to a project. Discounting financial outlays, on the other hand, reduces the cost of creating carbon offsets. Since most outlays occur early on in the life of a forest project, costs of creating carbon offsets are not as sensitive to the discount rate used for costs as to the discount rate used for carbon.

Emissions trading: a process to control pollution whereby a central authority (e.g. a regional or national body, or an international body) sets a limit or cap on the amount of a pollutant (e.g. carbon dioxide) that can be emitted. It is sometimes called cap and trade. Companies or other groups are issued emission permits and are required to hold an equivalent number of *allowances* (or credits) that represent the right to emit a specific amount. The total amount of allowances and credits cannot exceed the cap, limiting total emissions to that level. Companies that need to increase their emission allowance must buy credits from those who pollute less. The transfer of allowances is referred to as a trade. In effect, the buyer is paying a charge for polluting, while the seller is being rewarded for having reduced emissions by more than was needed. Thus, in theory, those who can easily reduce emissions most cheaply will do so, achieving the pollution reduction at the lowest possible cost to society.

Externalities: an effect of a purchase or use decision by one set of parties on others who did not have a choice and whose interests were not taken into account. In such a case, prices do not reflect the full costs or benefits in production or consumption of a product or service. A positive impact is called an *external benefit*, while a negative impact is called an *external cost.*

Flexibility mechanisms: market-based mechanisms in the Kyoto Protocol which are intended to support Annex B countries in meeting their emissions limitation/reduction targets at least costs. These mechanisms are Emissions Trading, the Clean Development Mechanism and Joint Implementation. Annex 1 countries can invest in J1 and CDM projects as well as host J1 projects. Non Annex 1 countries can host CDM projects. Note that Belarus and Turkey are listed in Annex 1 but not Annex B; and Croatia, Lichtenstein, Monaco and Slovenia are listed in Annex B but not Annex 1.

Forest-based sector Technology Platform (FTP): has defined and is currently implementing a research and development roadmap for the European forest-based sector.

Global Warming Potential (GWP): a measure of the contribution made by a combination or mix of greenhouse gases to global warming, which involves converting quantities of non-CO_2 greenhouse gases to an equivalent amount of CO_2. Over an assumed 100-year time frame, the global warming potential of 1 tonne of methane is equivalent to 23 tonnes of CO_2 (or 24.5 tCO_2e) while 1 tonne of nitrous oxide is equivalent to 296 tonnes of CO_2 (or 320 tCO_2e).

Greenhouse gases (GHG): gases that have significant infrared radiation absorption bands in the troposphere. In order of importance, the relevant *natural* GHG in the troposphere are: water vapour, carbon dioxide (CO_2), methane (CH_4), ozone (O_3) and nitrous oxide (N_2O). UK forests exchange all of these GHG with the troposphere to a larger or smaller extent.

Joint Implementation (JI): as part of the Kyoto Protocol, allows industrialised countries with a greenhouse gas reduction commitment (called Annex B countries) to earn emission reduction units (ERUs) from an emission-reduction or emission-removal project in another Annex B country.

Marginal abatement cost (MAC): in economics, marginal cost is the change in total cost that arises when the quantity produced changes by one unit. It is the cost of producing one more unit of a good. A marginal abatement cost curve represents the marginal economic cost of one extra tonne of GHG mitigation.

Market price of carbon: reflects the value of traded carbon emissions rights to those in the market given the constraints on supply of these rights to emit imposed by current policy. If the carbon market covers all emissions and is competitive, then the market price will be equal to the MAC for a given target.

Maximum mean annual increment (MMAI): the average rate of volume growth from planting/regeneration to any point of time is known as the 'mean annual increment'. This value will increase during the early phases of stand development (i.e 'stand initiation' and 'stem exclusion') before reaching a peak and then declining. This peak value is known as the 'maximum mean annual increment' (MMAI) and will vary between species and sites. It provides an estimate of the maximum average rate of volume production (and hence carbon sequestration) that can be maintained on a site in perpetuity. In conifer species, the age of MMAI usually occurs towards the end of the 'stem exclusion' phase.

Mitigation: (of global warming) actions to decrease GHG emissions, to enhance sinks, or both, in order to reduce the extent of global warming.

Opportunity costs: income foregone – for example, the net income which would have been achieved by a crop now replaced by an alternative land use. For example, the costs of woodland creation may not only be the establishment costs. This value has to be considered in the economic calculations.

Sequestration: (of C or CO_2) the removal from the atmosphere of carbon or carbon dioxide through biological or physical processes and their retention in living biomass or wood products.

Shadow price of carbon (SPC): a shadow price in that it is the marginal abatement cost (MAC) to reach a target concentration, although that choice of target concentration depends on *social* valuation. Then the SPC might be measured by price that we *might* agree should be the carbon (dioxide) price that all (or most) countries would set internally (via taxes or cap and trade mechanisms) and which ought then to be equal to the MAC. The SPC is intended to guide decisions if incorporated into a market price, i.e. as a tax or allowance price, with rebates for other carbon pricing instruments (like the EU ETS). In practice, decisions as well as investment are guided by market prices. Whereas the social cost of carbon (SCC) is determined purely by our understanding of the damage caused and the way we value it, the SPC can adjust to reflect the policy and technological environment. This makes the SPC a more versatile concept in making sure that policy decisions across a range of government.

Social cost of carbon (SCC): measures the full global cost today of an incremental unit of carbon (or equivalent amount of other GHG) emitted now, summing the full global cost of the damage it imposes over the whole of its time in the atmosphere. It measures the scale of the externality, i.e. *social* cost of the damage caused by releasing a tonne of CO_2. Its magnitude depends on the choice of the social welfare function and its implied social weighting scheme (which is that adopted by the *Stern Review* and the Government *Green Book*) and on the rate of pure time preference. The SCC matters because it signals what society should, in theory, be willing to pay now to avoid the future damage caused by incremental carbon emissions. The SCC is conceptually different from the market price of carbon.

Transaction costs: (in economics) is a cost incurred in making an economic exchange.

Yield Class: in the British system Yield Classes are created by splitting the range of possible MMAI (see definition above) into steps of two cubic metres per hectare. Thus a stand of YC 14 has a maximum MMAI of about 14 $m^3 ha^{-1}$, i.e. greater than 13 but less than 15 $m^3 ha^{-1}$.

Units

tC	tonne of carbon
1 Mt	megatonne equivalent to one million tonnes (1 Mt = 1 000 000 tonnes)
1tC	equivalent to 44/12 (roughly 3.67) tonnes of carbon dioxide (CO_2)
CO_2e	CO_2-equivalent – see Glossary for definition
1 GJ	gigajoule – unit of energy equivalent to one thousand million joules
1 Gt	gigatonne – unit of mass equivalent to one thousand million tonnes
odt	oven dried tonnes
Mtoe	million tonnes oil equivalent
ppmv	parts per million by volume

Abbreviations

ACF	alternative to clearfell
ARD	(under the Kyoto Protocol) 'afforestation, reforestation and deforestation' activities (and consequent changes in forest area) since 1990
BAU	business as usual
CCC	Committee on Climate Change established by the UK Climate Change Act 2008 to advise Government
CCF	continuous cover forestry
CDM	Clean Development Mechanism – see Glossary for definition
CHP	Combined heat and power
DECC	Department of Energy and Climate Change
FC	Forestry Commission
FMA	forest management alternative (see Chapter 6)
FMS	forest management scenario
FTP	Forest-based sector Technology Platform – see Glossary for definition
GGS	Green Guide for Specification. Building Research Establishment guide www.thegreenguide.org.uk
GHG	greenhouse gas(es) – see Glossary for definition
GWP	Global Warming Potential – see Glossary for definition
HWP	harvested wood products
IPCC	Intergovernmental Panel on Climate Change of the United Nations
LISS	low-impact silvicultural system
MAC	marginal abatement cost – see Glossary for definition
MMAI	maximum mean annual increment – see Glossary for definition
SRC	short rotation coppice
SRF	short rotation forestry
UNFCCC	United Nations Framework Convention on Climate Change
YC	Yield Class – see Glossary for definition

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