



Woodland and our changing environment



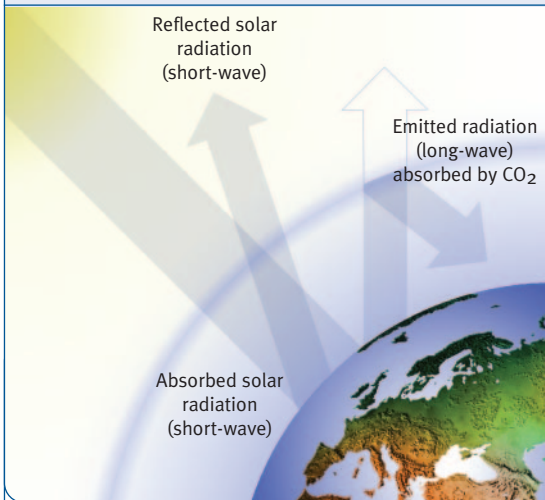
by Dr Mark Broadmeadow

Introduction

Forests and woodlands are important parts of the landscape of the UK, covering over two and a half million hectares (an area slightly larger than Wales), which is 12% of our total land area. The tree species native to the UK have gradually adapted to the local climate, atmosphere and soils since the last glaciers retreated over 10 000 years ago. Human activities have resulted in many changes to this natural environment, especially during the past 200 years. Foremost among the environmental issues that can affect trees are climate change and the ‘greenhouse effect’, acid rain, and nitrogen enrichment. In addition, many of these aspects of environmental change interact with existing problems – such as disease and insect outbreaks, drought and temperature extremes – and make them more severe. Human-induced environmental change adds to the potentially devastating effects of extreme weather events, such as the drought in the summer of 1976 and the storm of October 1987. This factsheet explores some of the difficulties that the changing environment presents for trees in the UK, and suggests how this situation might change in the future.

What is the greenhouse effect?

Certain gases – mainly carbon dioxide (CO₂) but also methane (CH₄), nitrous oxide (N₂O) and volatile organic compounds (VOCs) – play an important role in regulating the temperature of the earth's atmosphere. These are known collectively as 'greenhouse gases'. Most visible and ultraviolet light coming from the sun is able to reach the earth's surface by passing through the atmosphere. Some of this energy is re-radiated back to space in the form of long-wave or infrared radiation. Natural amounts of greenhouse gases maintain the earth's temperature at a habitable level by absorbing some of this energy – the 'greenhouse effect'. However, human activities are increasing the concentrations of greenhouse gases in the atmosphere, leading to a gradual warming of the earth's climate. It is this *enhanced* greenhouse effect that is generally referred to as global warming.



The greenhouse effect. Some of the solar energy re-radiated by the earth is absorbed by greenhouse gases. Increased levels of CO₂ cause more heat to be retained.

Global warming and climate change

Human activities, such as deforestation and the burning of fossil fuels, have resulted in an increase in the concentrations of greenhouse gases in the atmosphere. The most important of these gases is carbon dioxide (CO₂), which has risen from a concentration of 275 parts per million (ppm) prior to 1850 to the current value of 375 ppm. Levels of CO₂ are expected to continue rising, and current estimates predict a concentration of 525–950 ppm by the end of this century. The enhancement of the greenhouse effect by rising concentrations of these gases is largely responsible for the issue of global warming that has recently received so much media attention. However, rising temperatures are only one consequence of the enhanced greenhouse effect; changes to weather patterns and many other aspects of climate, such as rainfall and humidity, are also predicted. Collectively, these are referred to as 'climate change'.

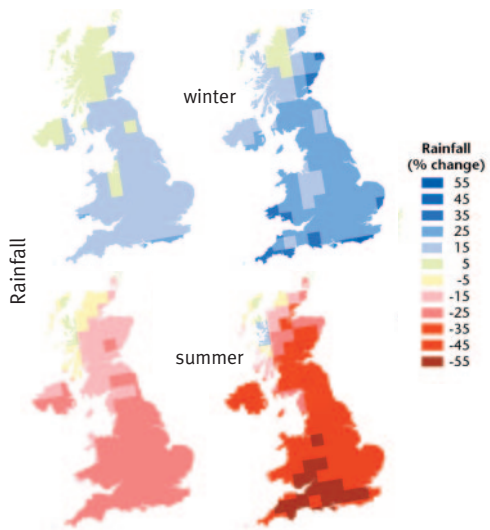
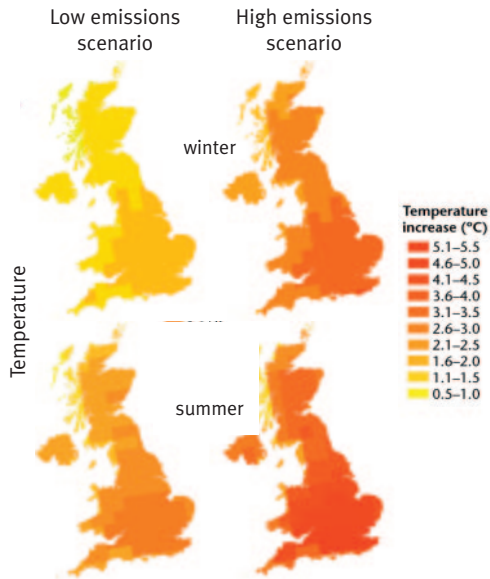
Predictions of the future climate have been made using computer simulations based on assumed rates of increase of greenhouse gas concentrations. In the UK we will probably experience milder, wetter winters, while the summer months will be hotter and drier. The changes will be most apparent in southern England, with winter flooding and severe summer droughts becoming increasingly frequent. Our climate is also predicted to become more variable, with an increase in the frequency of extreme weather events such as floods and storms. Predicted changes in temperature and rainfall for the 2080s are compared for summer and winter in the maps of the UK shown on page 3, although we cannot be sure which of the scenarios is more likely. This is partly because of uncertainty in the science of climate change, but also because we do not know how the global economy and its associated greenhouse gas emissions will develop.

The way that the environment (including climate) affects tree growth can be visualised as changes to a series of processes, as shown in the diagram on page 3. The balance between these processes leads to faster or slower tree growth. Climate change could alter some of these processes, improving the growth and health of trees in a number of ways:

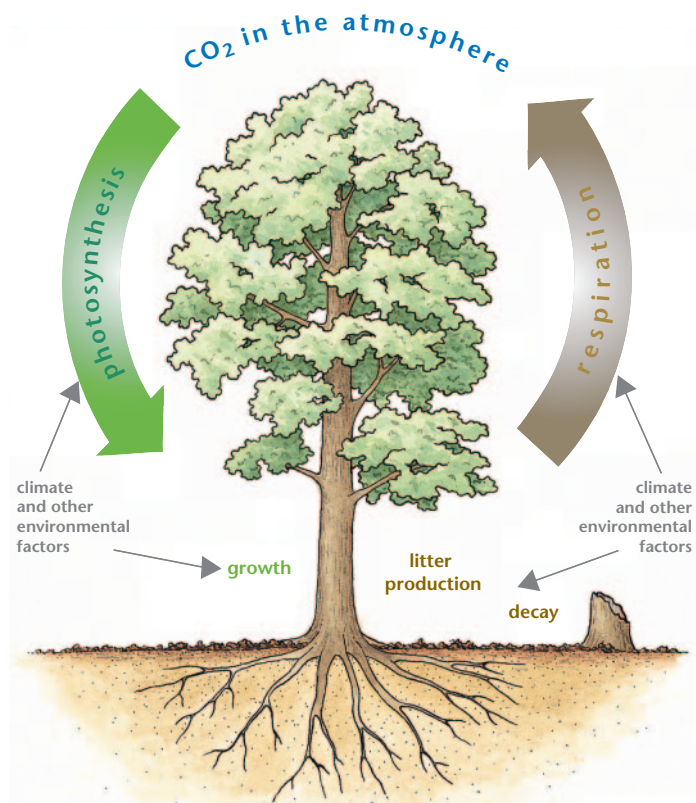
- Elevated CO₂ concentrations in the atmosphere act as a fertiliser for plants, allowing more photosynthesis to take place and resulting in faster growing trees. Experiments on young trees in many countries have shown growth increases of, typically, 35%. However, it is uncertain whether this 'CO₂ fertilisation effect' will occur to the same extent in mature woodland.
- Leaves will lose less water at higher CO₂ concentrations. However, this advantage may be offset by the increase in total leaf area often observed in experiments.
- In the UK warmer weather, particularly in winter, is likely to lead to longer growing seasons and improved tree growth.
- Cold and snow-related damage are likely to become less common.
- There will be opportunities to plant species which are currently not planted because they are sensitive to winter cold.

Will the greenhouse effect harm trees and forests?

Some of the carbon dioxide (CO₂) in the atmosphere is taken up by plants and converted into carbohydrate through the process of photosynthesis. This process is dependent on the concentration of CO₂ in the atmosphere and on climate and other environmental factors including: temperature, rainfall, humidity, water availability and sunlight. At the same time, other processes such as the respiration of living plant material and the decay of dead plant tissue are converting carbohydrate back to CO₂. These processes are mainly dependent on temperature. Any factor which changes the contribution of any of the processes, including the supply of nutrients such as nitrogen and phosphorus, may alter the growth or condition of trees and woodland.



Changes in temperature and rainfall predicted for the 2080s, under Low and High greenhouse gas emissions scenarios. [UKCIP02 scenarios, funded by Defra, produced by Tyndall and Hadley Centres for UK Climate Impacts Programme.]

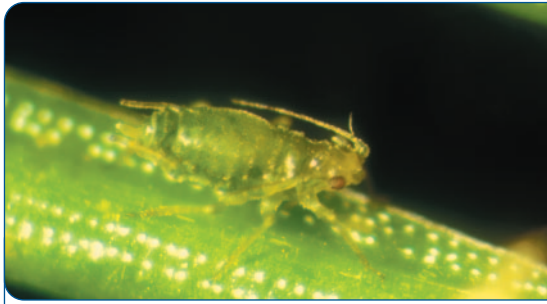


However, countering these positive effects, there are a number of potential problems:

- Trees may become more susceptible to damage from late spring frosts as a result of earlier leafing.
- In the south of England, less summer rainfall may reduce tree growth and, as climate change progresses, severe summer droughts may kill increasing numbers of trees, particularly species such as birch and beech.
- Violent storms may occur more often, and more trees are likely to be blown down or suffer wind-snap. The predicted increases in wind speed are largest in the south and in winter. However, changes to the wind climate are the least certain of the climate change predictions and should be viewed with caution.



A horse chestnut tree in southern England damaged during the 1987 storm.



The green spruce aphid which is a serious pest of Sitka spruce may increase in numbers as our climate becomes warmer.

- Some indigenous pests may become more prevalent and woodlands may become more vulnerable to new or exotic pests and diseases.
- A changing climate is likely to alter the character and makeup of native woodland plant communities.

It is not yet possible to say with certainty how these effects will balance out and which are likely to be most important. Current thinking is that, over the course of the next 50 years, climate change is likely to be beneficial to tree growth over large parts of the UK. However, in individual years and particularly in the south, reduced water availability in summer may have dramatic impacts on species suitability and productivity. Adaptation of forest design and management will become increasingly necessary as climate change progresses.

The greenhouse effect and forests: a global perspective

As described on the previous page, trees lock up CO₂ by accumulating carbon while they are growing. Carbon makes up about half their dry weight. The carbon is released when trees die and decay or are cut down and burned. Over the past 200 years, carbon released into the atmosphere during land clearance and the burning of fossil fuels such as oil and coal has led to the greenhouse effect and consequent global warming.



Deforestation has contributed to the greenhouse effect.

A global commitment to reduce CO₂ emissions was signed in Kyoto, Japan, in 1997. Although emissions reduction is the focus of the *Kyoto Protocol*, the agreement also has provisions to encourage the protection and expansion of forests to help lock up carbon in the form of wood. Young forests that are growing quickly take up carbon; old, mature forests do not, since the amount of carbon taken up by photosynthesis balances the carbon that is lost through tree death and decay. In the UK, the total amount of carbon locked up or *sequestered* in all our woodland is estimated to be increasing by between two and three million tonnes per year. To place this in context, UK annual carbon emissions from all sources are about 150 million tonnes per year, or three tonnes for each person. Although the contribution from our woodland may seem small, it is important, since all reductions in carbon emissions and increases in the amount of carbon locked up will help to reduce the greenhouse effect in the future. A practical example of this is the estimate that one hectare of woodland will take up as much carbon as would be produced by two cars over the commercial lifetime of that woodland (40–60 years).



Wood products used in building or furniture could play a role in locking up carbon and reducing greenhouse gas emissions in the future.

Once an area of woodland has matured, it has reached its full potential for carbon sequestration; further carbon can only be locked up if the trees are felled, the wood used, and the land replanted for continuing carbon sequestration. Short-lived products such as paper contribute little, but the use of timber in buildings and furniture could be important, particularly if replacing materials such as steel and concrete which require large fossil fuel inputs for their production. If wood or parts of the tree that are not normally harvested at present were to be used to generate electricity or heat, replacing fossil fuels, this would also benefit the global carbon budget. We must therefore think carefully about how we use our forests, and the products derived from them.

What is 'acid rain'?

People often use the term *acid rain* incorrectly to refer to all types of air pollution caused by human activities. It is a confusing term because rainwater is naturally acidic. Much of this natural acidity is the result of carbon dioxide (CO₂) gas (which is naturally present in our atmosphere), dissolving in rainwater. Additional natural acidity comes from sources such as volcanoes.

Rainwater can become more acidic when man-made pollutants also become dissolved. This acidity is mainly derived from two gases produced during burning: sulphur dioxide (SO₂) and nitric oxide (NO) which quickly turns to nitrogen dioxide (NO₂). These react with water in the atmosphere to form sulphuric acid and nitric acid which are the most significant man-made acids in acid rain. Most of the SO₂ and NO₂ produced in Britain comes from power stations and large industrial units, but cars and heavy vehicles are also important sources of the oxides of nitrogen.



Acid gas emissions from UK industrial plants and power stations have reduced in recent years.



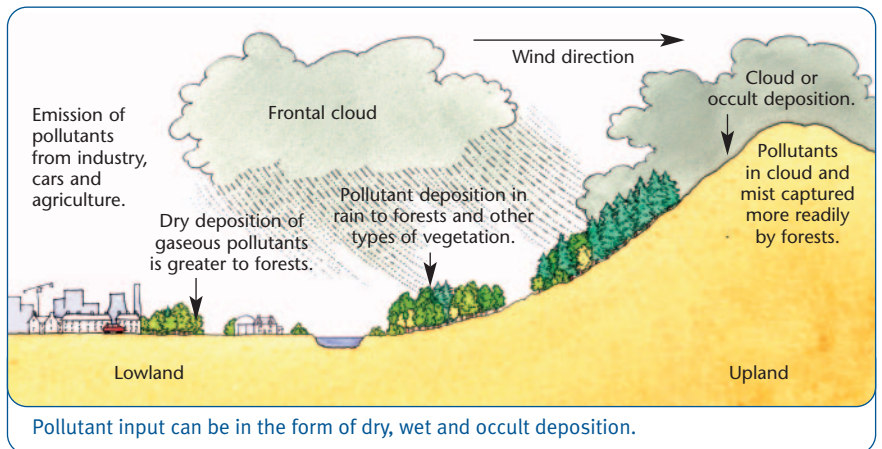
Deaths resulting from winter smogs in our cities led to the first pollution control strategies.

Air pollution

Acid rain

The by-products of burning fossil fuels such as coal and oil form the largest source of man-made acidity in the atmosphere. The proportion of man-made and natural acidity in rainwater is variable throughout Britain. In the west of Scotland it is estimated that less than half of the acidity is man-made, while in England up to 90% may be as a result of pollution.

In addition to acid pollutants entering the forest ecosystem through acid rain, often called *wet deposition*, there are two other processes through which forest soils and watercourses can be affected. Water droplets in the form of cloud, fog or mist can be many times more acidic than rainwater and these are deposited on forest canopies, especially in upland areas (*occult deposition*). The acid pollutants may also be deposited on the forest in the form of particles and gases (*dry deposition*) which will then be washed through to the soil by rainwater. Both occult and dry deposition of acidity is greater to forests than to other types of vegetation. This is because forests have many layers of leaves, and also because the 'rough' profile of the trees, in comparison to grassland for example, causes more pollutants to be trapped. However, although forests may lead to increased acid deposition, *it is not the trees that are causing the acidification*. They are simply better filters for 'cleaning up' pollutants in the atmosphere than other vegetation.



Pollutant input can be in the form of dry, wet and occult deposition.

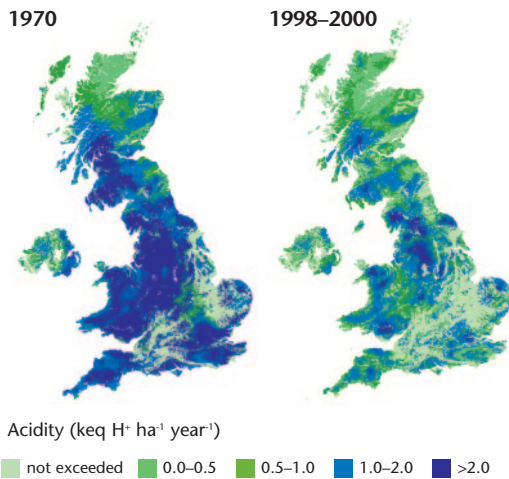
The history of acid rain

Acid rain first became a problem over 200 years ago in areas close to large industrial towns. Together with other forms of air pollution, acid rain became steadily worse until the middle of the 20th century. Then, following the acid fogs ('smogs') in the 1950s that contributed to the death of thousands of people in London, laws were introduced to reduce pollution in towns and cities.

Smokeless zones reduced the emission of some pollutants and tall chimneys spread the rest more widely. Control policies introduced in the 1990s further reduced emissions of sulphur from power stations and heavy industry. Acid rain is therefore not as serious a problem as it used to be.

What is a critical load?

Ecosystems including woodland can withstand the input of a limited amount of each pollutant. The level of pollution input below which damage to the tree, soil or ecosystem is thought unlikely, is known as the critical load. Where a critical load is exceeded, it does not always mean that damage will occur. Critical loads are set to protect ecosystems in the long term, and the effects of pollutants can take many decades to appear. Critical loads form the basis of emission control policies, providing an indication of where ecosystems are likely to be affected. Model simulations are then used to identify how best to reduce pollutant exposure.



Exceedances of critical loads of acidity are calculated from pollutant levels, soil type and land cover. Exceedance is now less widespread than in 1970, and largely restricted to areas of high rainfall and naturally acidic sites.
[Reproduced with permission from Centre for Ecology and Hydrology.]



Open-top chambers used to investigate the effects of ambient air pollution on tree growth.

This is shown in the maps in the left-hand column which compare the areas where the deposition of acidity has been calculated to exceed 'critical loads', i.e. *more than the ecosystem can cope with*, for 1970 and 1998–2000. Model simulations for 2010 predict further improvements if planned emissions control measures, agreed as part of the *Gothenburg Protocol* in 1999, are implemented.

What effect is acid rain having on the environment in Britain?

It is known that the increase in the acidity of some lakes and rivers in the 1980s was mainly due to acid rain. In some cases fish have disappeared or failed to breed, and birds that feed in streams have decreased in numbers. The most affected areas were those where the rocks are naturally acidic and the soils are thin. Where rocks contain a lot of chalk or limestone, the acidity is neutralised as it enters and passes through the soil.

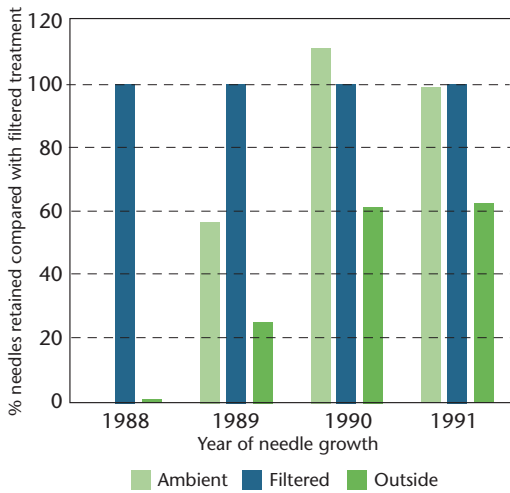
Many forest soils have also become more acidic although, so far, no adverse effects have been seen on trees associated with this form of acidification. However, we cannot say that damage at levels too low for detection has not occurred and, so in order to protect the environment from further possible damage, the critical load approach has been introduced. Critical loads of acidity are assessed for sites where it is planned to plant trees. If the extra acidifying effects of trees would be likely to lead to the critical load being exceeded, they are not planted.

The direct effect of acid deposition on trees, as distinct from indirect effects through the soil, are also unclear. Experiments have shown that rain at the sort of acidity level that is normally found in Britain does not directly damage the leaves of most trees. However, fog and mist can sometimes be very acidic and may then cause direct damage. One example was recorded in southeast England in September 1989 when a highly acidic fog, originating in the industrial area of continental Europe, damaged the leaves of many trees.

The effects of sulphur dioxide, ozone and other gases

Some gases which contribute to acid deposition also have the capacity to harm both trees and ecosystems in their own right. To study their effects, the Forestry Commission and Forest Research set up an experiment in 1987 to investigate the effects of air pollution on tree growth.

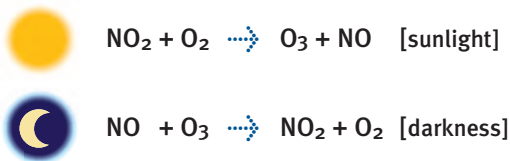
Trees were planted in special growth chambers, known as *open-top chambers*, at three sites which covered the range of pollution environments experienced in the UK. One was a 'clean air' site in the Scottish uplands, one was in the English Midlands where sulphur dioxide and nitrogen oxides levels had been high, and the third site was in southern England where the pollution climate was dominated by ozone. The chambers allowed comparisons to be made between trees growing in the normal 'ambient' air at the site, and trees growing in clean, 'filtered' air. Trees were also grown outside to identify the effects of the chambers themselves. Different species were affected in different ways, with the largest reductions in growth observed in Norway spruce in the south of England, and beech



Needle retention in Scots pine following exposure to ambient air pollution in open-top chambers, filtered air in open-top chambers and ambient air outside the chambers.

What is ozone?

Ozone is produced in complex chemical reactions which take place under the influence of sunlight, and result in nitrogen dioxide (NO₂) combining with oxygen (O₂) to produce ozone (O₃) and nitrous oxide (NO). The generation of ozone is enhanced by the presence of volatile organic compounds (VOCs). The reverse reaction occurs at night, and so we see large daily changes, with peak concentrations of ozone generally experienced in the late afternoon. Ozone concentrations are also often lower in built up areas than in rural areas because the nitrous oxide in vehicle exhaust emissions breaks down the ozone. Ozone formed in this way is referred to as a photochemical oxidant. Even more damaging compounds may be produced in highly polluted areas in a similar way, but we know less about them.



Ozone is produced in complex chemical reactions (summarised above) which take place under the influence of sunlight. The reverse reactions occur at night.

and Sitka spruce in the English Midlands, as shown in the table below. In some cases, growth appeared to be better in the ambient, polluted air than in filtered air. This may be because at low concentrations, these pollutants act as fertilisers. Apart from reduced (or increased) growth, other effects were apparent, such as needles being retained for a shorter period at the site in southern England, as shown in the graph in the left-hand column.

The effect on tree growth after four years in ambient air compared to filtered air.

	Southeast England	English Midlands	Scottish uplands
Beech	-14	-44	n/p
Norway spruce	-40	+32	-14
Sitka spruce	n/p	-40	+23
Scots pine	-7	-9	-3

The results of this experiment are expressed as % difference in stem weight between ambient and filtered air, with negative numbers indicating a harmful effect, and positive numbers, a beneficial effect. n/p: not planted.

Sulphur dioxide

Sulphur dioxide (SO₂) is mainly derived from burning fossil fuels and its harmful effects have been known about for a long time, with many documented cases where trees close to some factories and power stations have been seriously damaged. In addition, poor tree growth was observed in the more polluted parts of Britain such as the south Pennines. The concentration of SO₂ in the atmosphere has fallen greatly over the past 20 years as a result of emissions control measures and it is now considered to be less of a threat to tree health than other pollutants such as ozone and ammonia.

Ozone

A discussion of ozone and environmental change or pollution can lead to confusion. It is important to distinguish between ozone in the upper atmosphere (stratospheric ozone) which protects us from the sun's harmful rays, and ground level (tropospheric) ozone, which is a pollutant, causing damage to both trees and humans.

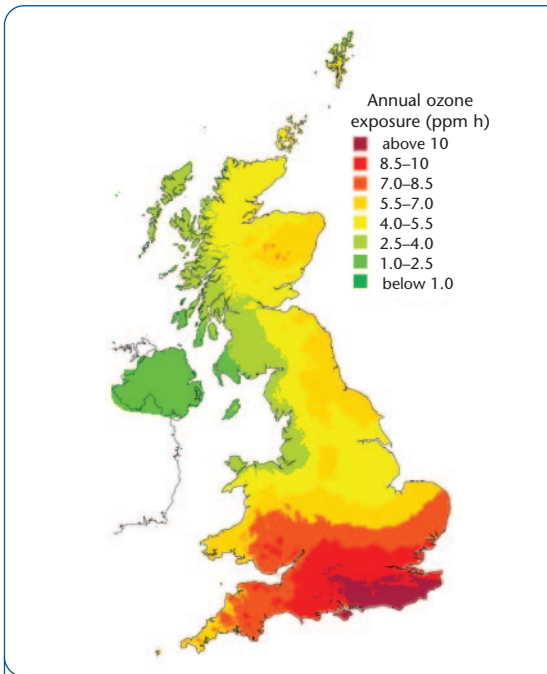
Ground level ozone

Ground level ozone is naturally present at low concentrations, but problems arise when pollution raises these concentrations. A well-known example of this is in California, where the smogs largely consist of ozone and other related gases. There, people are sometimes warned to stay inside because the pollution levels are so high.

Background concentrations of ozone have been increasing slowly in recent years, although peak concentrations in summer have fallen. This upward trend for ozone is therefore different to other pollutants and is the result of a global rise in the emission of the principal precursors to its formation – nitrogen oxides and volatile organic compounds (VOCs). Because of the global nature of the problem, emissions control measures at a UK or Europe-wide scale have less impact on ozone levels than for other pollutants such



Ozone pollution can lead to characteristic visible injury to leaves in some woody species including ash (shown above), beech and wayfaring tree.



Ozone exposure is highest in southeast England. Exposure above 5 ppm h can lead to effects on the growth or physiology of trees. The index of ozone exposure used here is the accumulated exposure over a threshold of 0.04 ppm in units of parts per million hour (ppm h). [Reproduced with permission from Centre for Ecology and Hydrology.]

as SO₂ and nitrogen dioxide (NO₂). Predictions are for ozone concentrations to continue rising with ozone pollution becoming more and more important during this century.

High ozone concentrations can cause characteristic visible injury to the leaves of trees, varying from reddening, bronzing and the formation of black stipples to yellowing (chlorosis) and cell death (necrosis). In addition to such visible injury, ozone can reduce growth by damaging cell membranes and the photosynthetic system, and it also makes trees more susceptible to drought by affecting their ability to conserve water. Ozone exposure in Britain regularly reaches the value at which this damage can occur, and across Europe as a whole it has been estimated that ozone pollution may reduce forest growth by about 10%.

Stratospheric ozone and the ozone hole

Ozone also occurs in a zone at very high altitude (20–30 km) within the atmosphere. Alongside other gases such as water vapour, the ozone acts as a protective layer, helping to prevent the sun's harmful ultraviolet (UV) rays from reaching the earth's surface. Some industrial pollutants such as chlorofluorocarbons (CFCs), chlorine and bromine are damaging this layer. The result is a thinning of the protective layer, particularly over Antarctica – the so-called 'ozone hole'. The atmosphere over northern Europe has so far been less severely affected. The concentrations of the ozone-depleting chemicals in the atmosphere have now stopped rising, but the ozone layer is unlikely to recover until the middle of this century.

The thinning of the ozone layer has serious implications for human health because the increase in UV radiation at the earth's surface can increase the risk of skin cancer. Our knowledge of the effects of UV radiation on plants is limited, but the evidence suggests that mature trees are largely unaffected by the level of thinning of the ozone layer that has so far been seen over the UK. However, the surface waxes and cells of young leaves may be damaged by UV light. The ozone hole is a serious global problem, and both monitoring and research must continue to help prevent the thinning from spreading or getting any worse.

Oxides of nitrogen and ammonia

All plants need nitrogen to grow. They may absorb it through their leaves in the form of gases (nitrogen dioxide or ammonia), or from the soil water in the form of ions (nitrate and ammonium). Although nitrogen is an essential nutrient, trees can receive more of it than they need and this may have indirect effects on their health and growth. In general, the concentrations of nitrogenous compounds that build up in trees are not enough to cause them direct damage, but the rapid growth that is induced can lead to an imbalance in the supply of other nutrients such as magnesium and phosphorus. Moreover, some insects, particularly aphids, seem to favour trees with high nitrogen levels and so nitrogen enrichment may result in increased levels of insect attack. Although there is no direct evidence of nitrogen pollution detrimentally affecting tree growth in Britain, both needle retention and the incidence of insect damage to Scots pine did appear to be related to nitrogen deposition in a recent survey of forest condition.



Agricultural ammonia emissions are becoming an increasingly important contributor to nitrogen deposition.



Monitoring changes to the ground vegetation of woodland helps to identify the effects of excess nitrogen deposition.



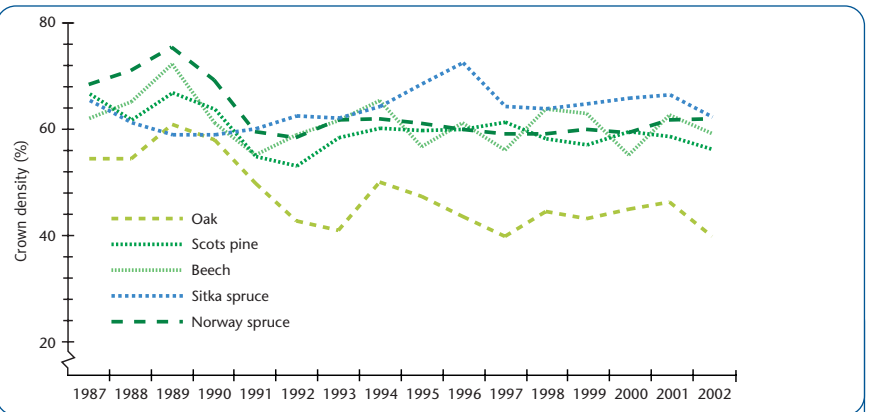
Forest condition is monitored at over 300 plots by an annual assessment of crown density.

The build up of large quantities of nitrogenous compounds can have damaging effects on the wider environment in a process known as *eutrophication*. This can lead to major changes in natural ecosystems, including the accumulation of green algae in watercourses ('algal blooms') and the conversion of rare heathland habitats to grassland. Excessive nitrogen inputs can also lead to acidification of soils. Nitrogen dioxide from power stations, large industrial units and vehicle exhaust emissions does contribute to nitrogen enrichment. However, the largest contributor is often ammonia emissions, mainly from livestock farming, and is a significant problem in areas such as East Anglia. Here, the nitrogen input to forested areas may be over 40 kg per hectare per year, although these values are low compared to some other areas of Europe.

Excess nitrogen deposition and eutrophication is already a problem, and has the potential to become much worse. Models indicate that critical loads for nitrogen are exceeded for the majority of woodland in the UK. These critical loads were set to protect the soil and ground vegetation rather than the trees. There is some evidence that there have been subtle changes to the ground vegetation with a trend towards more nitrogen demanding species, particularly close to woodland edges.

How is pollution affecting our woodlands and forests?

All member states within the European Union carry out forest condition surveys every year. In the UK there are about 360 forest condition plots covering five species (oak, beech, Scots pine, Sitka spruce and Norway spruce). The condition of the tree crowns in these plots has been assessed since 1987, and these results are published annually by the Forestry Commission. The results from 90 of these plots are fed into a wider European survey which comprises over 6000 plots. In addition to crown condition, measurements are made of tree growth and the nutrient levels in soil and foliage. At 10% of sites, even more detailed studies have been carried out since 1994 by recording pollutant deposition, weather, canopy development and changes in the chemical composition of the soil water. These investigations are designed to identify long-term trends in forest condition and to help explain the causes of these trends.



Trends in UK forest condition since 1987. Every year, nearly 9000 trees are assessed in over 300 plots. Condition is measured as the % reduction in crown density relative to an 'ideal' tree.



Intensive monitoring plots help to identify the underlying causes for any observed trends in forest condition.

Across Europe, there has been a deterioration in crown condition in a number of species since 1989. There are large regional variations, with eastern Europe and the Iberian peninsula most badly affected. Different species also react differently, but so far, it has not been possible to identify the cause of this deterioration with certainty. Indeed, it is likely to be the product of several factors rather than a single one.

In Britain, crown condition has varied over the past fifteen years, and some of the more marked changes can be explained by known causes. For example, deterioration in Sitka spruce in 1997 (against a background of gradually improving crown condition) was caused by insect infestation; part of the fluctuation in the condition of beech has been due to poor leaf production in years when large quantities of seeds were produced (1991, 1995, 1997 and 2000), and this species also appears to be badly affected by drought. However, the most worrying trend is 'oak die-back'. Oaks have undoubtedly been affected in recent years by a combination of drought, late spring frosts, insect attack causing defoliation and soil pathogens causing root death, but so far, this decline has not been satisfactorily explained, and it remains an area of further research.

None of the many experiments and observations that have been made give any strong reasons to believe that pollution is seriously affecting the health of trees in the UK. However, the fact that there is no visible damage to the trees does not mean that their growth has not been reduced, or that there have not been some hidden effects. This presents a difficult challenge – if we cannot see damage, how do we know if the forests are under threat? A second challenge is how to distinguish between the different potential causes of tree decline – climate change, pollution, insects and diseases, storms and many others.

How can research progress?

Because there are so many interacting factors that could affect tree health and growth, and so many of them are changing as a result of human activity, simple experiments investigating the effects of single factors are seldom sufficient. However, as a result of improvements in information technology, we are now able to analyse the results of many of these experiments using models of tree growth. In combination with further research and carefully planned monitoring programmes such as the forest condition plots described previously, we will eventually be able to identify the underlying causes behind observed trends in forest condition.

It is important also to consider the wider ecosystem as well as any effects of pollution or environmental change on the trees themselves. Trees may be the most robust element of a woodland ecosystem, and therefore be the last to show signs of damage. The functioning of the whole woodland ecosystem thus requires protection against a changing environment. Although we have seen that trees so far have been largely unaffected, the effects of nitrogen deposition on ground vegetation are becoming clear, while changes in the distribution of a number of plant and invertebrate species are becoming apparent, possibly as a result of climate change.



Research is continuing into the interactions between forests and water quantity and quality.



Wider landscape planning can help make woodland ecosystems more robust in a changing environment.

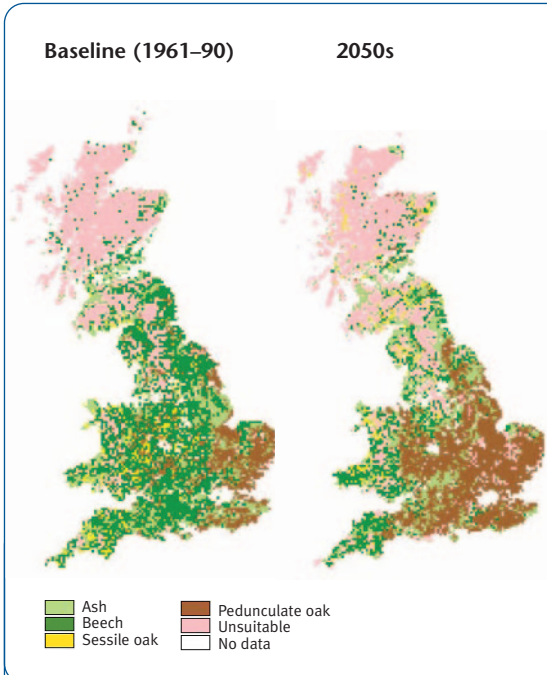
The functioning of ecosystems at a landscape level is equally important, with larger areas of woodland together with woodland networks likely to provide the most robust ecosystems as environmental change progresses.

Current research issues

After three decades of research, our knowledge about the threat of pollution to our forests has improved considerably – indeed, the value of trees as filters to clean the atmosphere of pollutants and particles is now being investigated, especially in the urban environment. The focus of research is now on achieving a better understanding of the ways in which trees interact with their environment and how they respond to climate change, placing particular emphasis on how forests can be managed to maximise their wide range of benefits.

We have learned a great deal about the interactions between forestry and the environment, and many of these findings have been used to improve management practice and protect woodland. However, we still need to know more about:

- How trees affect the water quality in rivers and streams.
- How trees may affect the position of water tables in dry conditions.
- How woodland can be managed to adapt to climate change.
- How woodland will respond to predicted changes in the pollution climate.
- How the landscape should be managed to provide more robust ecosystems capable of adapting to environmental change.
- How trees and forests can be used effectively as sources of renewable energy.
- How forest soils can be conserved and protected.



Research will provide guidance on the most suitable species to be planted to accommodate the climate change predictions. The maps show predicted changes to the most suitable broadleaved tree species as a result of climate change, based on model simulations.

These and many other issues are the subject of research, both in the UK and across Europe. Ongoing monitoring programmes are also essential for providing information on the extent and scale of changes to forest ecosystems. The increased understanding that will come from these studies will enable woodland to be better managed to withstand a changing environment and meet the increasing demands that are placed on it.

Web addresses

Climate change

www.ukcip.org.uk
www.ipcc.ch
www.ecn.ac.uk
www.nbu.ac.uk/ukcarbon
www.eci.ox.ac.uk/biodiversity/monarch.html
www.defra.gov.uk/environment/climatechange
www.forestry.gov.uk/forest_research/carbon

Air pollution

www.nbu.ac.uk/negtap
www.aeat.co.uk/netcen/airqual/reports
www.critloads.ceh.ac.uk
www.defra.gov.uk/environment/statistics/airqual
www.emep.int
www.es.lanacs.ac.uk/people/cnh

Forests and the environment

www.forestry.gov.uk/sustainableforestry
www.forestry.gov.uk/environmentalresearch
www.icp-forests.org
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