Comisiwn Coedwigaeth Cymru
Forestry Commission Wales

Research Note

Impacts of climate change on forestry in Wales

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July 2008

Climate change is now one of the greatest global challenges, and research is under way to establish the likely impacts on many aspects of the environment. Forestry Commission Wales has commissioned Forest Research to determine how forests and forestry in Wales will be affected by climate change. This Research Note provides an initial synopsis of the likely impacts, with preliminary recommendations to support the revision of the Wales Woodland Strategy. Climate change will create challenges and opportunities for the Welsh forest industry. Productivity will increase in some areas and a wider selection of species will become suitable, but effects will vary spatially and by species. New approaches to woodland management will be required to address potential threats of drought, increased pest and disease damage, and wind damage. There are many uncertainties associated with climate change, and the likely impact on trees, management systems and forest operations. A key concept in risk planning and management is diversification: from broadening the choice of genetic material, mixing tree species in stands, to varying management systems and the timing of operations. An aspiration of the current Wales Woodland Strategy is to increase the proportion of woodlands managed using low impact silvicultural systems. This conforms with the need to adapt management through species choice, promote management that has a lower environmental impact on forest sites, and improve the overall resilience of woodland ecosystems to climate change.

Introduction

As trees take many decades to mature, forestry must anticipate much further into the future than other land-management sectors. Although our knowledge about the likely effects of climate change is continually improving, we cannot wait until our predictive research is perfect (it never will be) to develop policies that address climate change. Uncertainty is no excuse for inaction and there are 'no-regrets' measures that can be implemented now to ensure that Welsh woodlands and the forestry sector continue to supply the needs of society. This work represents an initial exploration of climate-change impacts and the consequent opportunities and threats for forestry in Wales on which to base emerging adaptation measures.

Information has been compiled from the knowledge of forest scientists, and from tree species suitability modelling using the decision-support tool Ecological Site Classification (ESC) (Ray *et al.*, 2002; Broadmeadow and Ray, 2005). ESC species suitability distributions have been derived from knowledge-based models. Maps are indicative, using coarse-resolution soil information together with future climate variables derived from climate projections published by the United Kingdom Climate Impacts Programme (UKCIP) (Hulme *et al.*, 2002) at 5 km resolution. It is very important that the maps are used only to infer general trends, and that forest planning for the future climate involves careful site-specific and stand-specific assessment.

Assumptions

- Climate change in the manner described by the Intergovernmental Panel on Climate Change (IPCC) and UKCIP is accepted.
- For demonstration of the uncertainty associated with climate emissions scenarios, the UKCIP High- and Low-emissions scenarios* are shown for four species for the 30-year climate period centred on 2050. Projections of potential suitability changes on other species and for 2080 are downloadable from www.forestresearch.gov.uk/climatechangewales.
- The modelling work relies on spatial data of low resolution and so cannot be applied reliably to individual sites.
- The models provide an assessment of tree species' suitability for climatic averages, and do not include effects of extreme events or the introduction of new pests and diseases.
- Assessments of impacts are preliminary, and are likely to change as knowledge improves and as the climate change scenarios and projections are refined.
- There is already substantial evidence for recent change in the climate of Wales (see Jenkins *et al.*, 2007).

*The High-emissions scenario assumes rapid global economic growth with intensive use of fossil fuels and the Low-emissions scenario, increased economic, social and environmental sustainability with cleaner energy technologies.

This Research Note is supplemented by further information on climate change in Wales from the Forest Research website (see www.forestresearch.gov.uk/climatechangewales). Details of this and other relevant sources are provided throughout the Note.

Key findings

- The expected warmer climate will improve tree growth nationally. Productivity will generally increase, by up to 2–4 cubic metres per hectare per year ($m^3\ ha^{-1}\ yr^{-1}$) for conifers on sites where water and nutrients are not limiting.
- The climate of central and eastern Wales is likely to remain favourable for growing broadleaved species capable of yielding high-quality timber.
- Except under the High-emissions scenario later this century, oak and ash suitability will remain high providing some security for robust native woodland habitats in Wales. However, the species assemblages of woodland communities are likely to change.
- Changes in the seasonal distribution of rainfall will cause more frequent summer drought and more frequent winter flooding.
- Changes in the frequency of extreme winds may cause more wind damage.
- Pest and disease ecology will change with the climate; for example, more frequent green spruce aphid attacks may reduce Sitka spruce growth in west, east and south Wales.

Emerging recommendations

- Low-impact silvicultural systems (LISS) and the use of mixtures are likely to provide the basis for secure adaptation strategies.
- Where other management regimes are used, a wider range of species and genetic material within a species will increase stand resilience in a changing climate.
- Acceptance of natural colonisation of some non-native but naturalised tree species (e.g. beech) in woodlands may be a valid adaptation strategy, but this must be reviewed where conservation is a major objective.
- Contingency plans need to provide an adequate response to the potential increase in occurrence of catastrophic wind damage, fire, and pest or disease outbreaks.

Climate change and climate projections for Wales

The concentration of carbon dioxide (CO_2) in the Earth's atmosphere is rising rapidly due to emissions from human activities. The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2007) reported that the atmospheric CO_2 concentration has increased to 383 ppm.

This far exceeds the natural range at any time in the past 650 000 years, as determined from ice cores. The burning of fossil fuels and tropical deforestation are thought to be the main causes of this rapid increase, and concentrations of greenhouse gases (which include CO_2) are expected to rise much further during this century (IPCC, 2007). Greenhouse gases in the atmosphere also trap energy and an increase in their concentration has caused global mean surface temperatures to rise. The warming is, in turn, causing changes in other climatic variables such as rainfall, humidity and wind speed, although there will be regional and local differences.

Climate change will have a significant effect on the climate of Wales, in particular:

- summers will become warmer and winters will become milder
- the rainfall distribution will change, leading to drier summers, particularly in eastern and southern areas, and winters will be wetter across Wales
- increased frequency of drought throughout Wales, and particularly in the south
- increased frequency of high-intensity rainfall in winter leading to a greater likelihood of flooding, landslips, wetter soils, and risk of soil erosion and sedimentation of watercourses
- less winter cold and fewer frost days
- likely changes in wind climate, possibly with more frequent strong winds.

Three climatic variables – temperature, rainfall and wind speed – are particularly important for tree species suitability, productivity and forest management in Wales.

1. *Temperature*. Accumulated temperature (AT) is a measure of the degree of warmth for plant growth throughout the growing season. It is measured as the accumulated number of degrees over 5 °C each day of the growing season. Plant growth begins at about 5 °C, and so in relatively cool climates (such as Wales) small increases in the mean daily temperature have a large effect on AT, and on plant growth. Over the past 40 years the mean temperature of Wales has increased by about 1 °C overall, with increases in each season leading to a longer and warmer growing season. The climate change projections published by UKCIP (Hulme *et al.*, 2002) for different emissions scenarios have been used to calculate AT for the future 30-year climatic periods centred on the years 2050 and 2080. Figure 1 shows AT for the baseline climatic period 1961–1990 and the AT projected for the 2050 Low- and High-emissions scenarios. It shows a projected general increase in AT, and a 40% increase for the warmest southern parts of the country, from 1800 to 2500 day-degrees.

Figure 1
Accumulated temperature distribution in Wales: a) baseline climate, 1961–1990; b) projection for 2050 Low-emissions scenario; c) projection for 2050 High-emissions scenario.

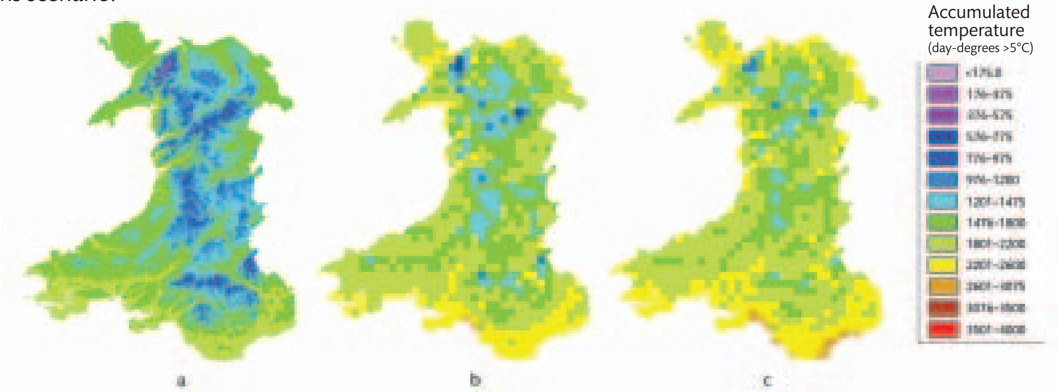
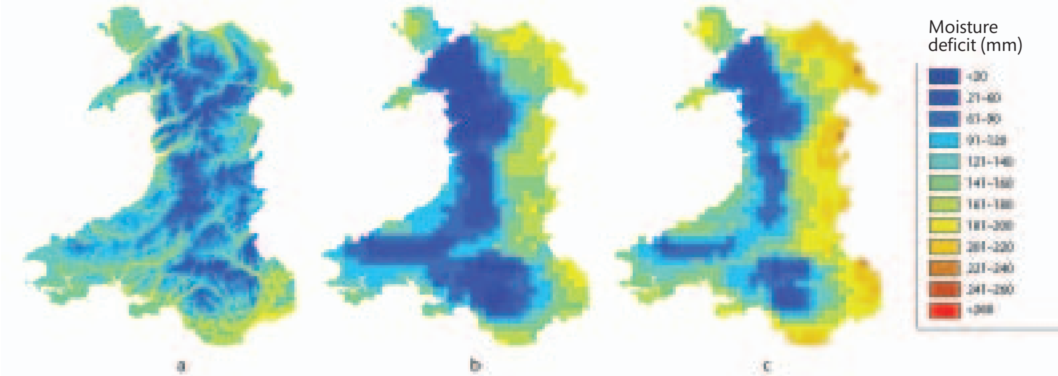


Figure 2
Moisture deficit distribution in Wales: a) baseline climate, 1961–1990; b) projection for 2050 Low-emissions scenario; c) projection for 2050 High-emissions scenario.



Note: Figures 1 and 2 show average climatic conditions projected for 30-year periods in the future, centred on 2050. The projections suggest a significant change in summer rainfall and evaporation in eastern and southern Wales, leading to drier summer conditions and more frequent summer drought. For many parts of west and north Wales, summer rainfall projections for 2050 are expected to maintain soil moisture through the growing season. Both figures are based on projections from the UKCIP 2002 Low- and High-emissions scenarios. For projected climatic conditions for 2080 see www.forestresearch.gsi.gov.uk/climatechangewales

For 2080 projections see online resources www.forestresearch.gov.uk/climatechangewales which show potential AT increasing to 3000 day-degrees in south Wales.

2. *Rainfall.* Moisture deficit (MD) is the maximum accumulated excess of evapotranspiration over rainfall in the summer months and is a good indication of water availability for plant growth. MD has been calculated for the climatic baseline period 1961–1990 and for the future 30-year climatic periods centred on the years 2050 and 2080. Figure 2 shows projected MDs increasing in the south and eastern lowlands of Wales from baseline climate values of 180 mm to values in excess of 200–220 mm for the High-emissions scenario by 2050, and 180–200 mm for the Low-emissions scenario. As many forest soils hold only 150–180 mm of water that is accessible to plants, many woodlands in Wales are likely to experience more frequent summer drought. The 2080 projections of MD are available online at www.forestresearch.gov.uk/climatechangewales.

3. *Wind speed.* Changes in the windiness of the climate are less certain. The climate predictions suggest only minor changes in the future mean wind speed. However, from the known relationship between mean wind speed and extreme events, it is possible that a small change in the mean could have a large influence on the frequency of extreme events.

Impacts of climate change on forests and species choice

A warmer climate will improve forest productivity for many tree species. A general increase in growth has been observed over the past 40 years (Cannell, 2002), and this has been attributed to increased warmth, increased CO_2 concentrations and improved silviculture. Recent research suggests that the increasing productivity is also due to higher nitrogen availability through decomposition and atmospheric deposition (Magnani *et al.*, 2007); however, in dry summers, productivity declines. Climate change will affect the suitability and therefore choice of tree species and provenance (i.e. origin). For example, Sitka spruce is relatively drought-sensitive and, on shallow soils, MDs in excess of 220–240 mm can cause moisture stress and stem crack. Climate change will also have consequences for the management of forests, particularly for species suitability and growth, disturbance and management.

Species suitability and growth

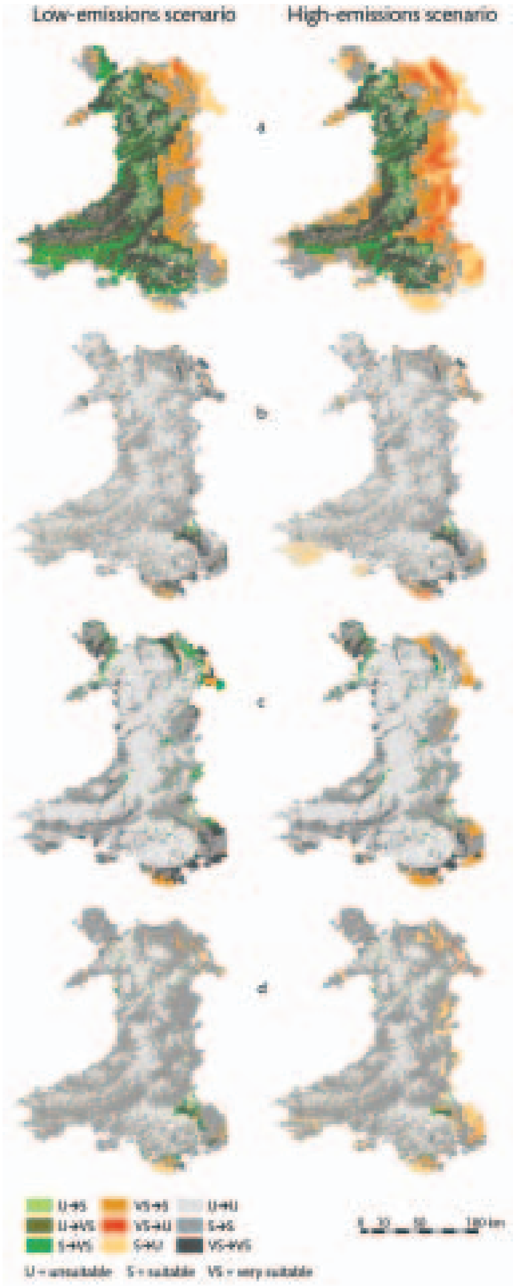
- Productivity is likely to increase (with another 2–4 $m^3\ ha^{-1}\ yr^{-1}$ likely for Sitka spruce) as a result of warmer summers where nitrogen and water resources are not limiting.
- Provenance choice will become an increasingly important consideration for some species, particularly those that perform better in a drier and warmer climate (Hubert and Cottrell, 2007). The inclusion of more southerly provenances within woodlands may increase resilience to climate change. However experience suggests that provenances taken from more than about 2° south of a site may have an unacceptable risk of frost damage under the current climate. It is also important to consider that although the climate will change, it will not become truly continental but will remain oceanic. This should be reflected in any decision over provenance choice.
- Change in the provenance of Sitka spruce currently used in Wales is not recommended (Samuel *et al.*, 2007). However, Douglas-fir provenance should be reviewed – material currently used in France may become well suited to the future climate of Wales. Site and climate matching tools may be used to confirm provenance and species suitability.
- The suitability distribution of many tree species is likely to change. Figure 3 shows changing suitability for a selection of species from the ESC spatial model. The figures are indicative, as they are based on attributes of the Soil Survey of England and Wales digital soil map of low spatial resolution (mapped at a scale of 1:250 000). Maps showing the predicted change in suitability of a wider range of species can be found at www.forestresearch.gov.uk/climatechangewales.
- The growing season will lengthen. Some species of tree will have earlier bud-burst and later dormancy, giving more frequent and prolonged lammas (late season) growth which may reduce timber quality.
- Using plant material from a wide range of provenances will help maintain and improve genetic diversity and the resilience of woodlands.
- The suitability of drought sensitive species will continue to decline in southern and eastern Wales. This suggests a new strategy of developing mixed species forestry, with diversity between or within stands.

Disturbance and management

- Mammal numbers including deer and grey squirrel are likely to increase. Milder winters with fewer frost days will reduce winter mortality, increase the recruitment of young, and increase damage to trees through browsing and bark stripping.
- A number of insect pests will become more prevalent. Milder winters will increase the size of over-wintering populations. Longer and warmer growing seasons may increase the development rate of insects and, for some, the number of generations per year. In addition warmer conditions and increased CO_2 will encourage development of more foliage for food – often shortening time to maturity.

- The epidemiology of tree diseases will change. For example:
  - Wetter and milder winters followed by droughty summers may predispose oak and other broadleaved species to root pathogens such as *Phytophthora cinnamomi*.
  - Since the 1990s red-band needle blight (caused by the fungus *Dothistroma septosporum*) has become widespread in Britain, mainly on Corsican pine, less so on other pines. This could be due to increased rainfall in spring and summer coupled with the trend towards warmer spring temperatures.

Figure 3
Indicative changes in the suitability of four species of tree in Wales by 2050 for Low- and High-emissions scenarios: a) Sitka spruce; b) Douglas-fir; c) ash; d) sessile oak. Green indicates increasing suitability; red/orange declining suitability.



Note: These maps are based on the UKCIP 2002 Low- and High-emissions scenarios, and are indicative maps using low resolution soil-quality data derived from Soil Survey of England and Wales digital data at a scale of 1:250 000.

- There is likely to be an increased threat from introduced pests and pathogens, as the climate becomes more favourable. Species of concern include oak processionary moth *(Thaumetopoea processionea)* and gypsy moth *(Lymantria dispar)*, and the European spruce bark beetle *(Ips typographus)*.
- Opinion favours mixing tree species within stands to reduce the impact of pests and pathogens.
- All emissions scenarios suggest that winters will be wetter in Wales, resulting in more waterlogged soil conditions. The increased winter rainfall will have a physiological impact on the rooting depth for many tree species, due to the presence of anaerobic conditions in which roots will not survive. Some tree species are particularly unsuited to sites with seasonally fluctuating water tables from very wet to dry conditions, especially beech and Douglas-fir.
- On imperfectly and poorly draining soil types, drought stress will become more critical when winter waterlogging is followed by summer drought, making trees more susceptible to pests and disease outbreaks.
- In dry summers there is evidence of increasing forest-fire frequency and an increase in the area of woodland damaged by forest fire (Broadmeadow and Ray, 2005). As the frequency of droughty summers increases, and given that forests are being increasingly used for recreation, it is possible that the occurrence of fires will also increase. Fire management plans should be adapted to consider changing risks due to climate change.

Additional adaptation issues

- Decision-support guidance is required to help forest managers adapt and manage for climate change and to inform national and local risk management strategies.
- For species that respond to temperature cues for bud-burst and dormancy, it will be necessary to consider and assess the risk of frost damage against other objectives. Despite the projection that frost will occur less frequently in the future, some risk will remain, particularly in inland areas away from the coast.

Impacts on silviculture and operations

Projections suggest that the climate will become more variable, with greater risk of extreme events (IPCC, 2007). Therefore, a primary objective of silviculture and management should be to spread risk in a way that reduces the impact of damaging events and increases the resilience of Welsh forests to climate change. This will require predictive forest planning informed by the types of damaging event likely and the type of site being managed. In this section, options for adapting forestry systems are considered, particularly in terms of stand management, site operations and coping with uncertainty.

Stand management

- Continuous cover systems of management on appropriate sites promote evolutionary adaptation through regular regeneration and also provide a less hostile environment for successful establishment.
- Mixing species in stands (or within the woodland), regardless of management system, will help to spread the risk associated with biotic and abiotic impacts. Wind exposure and the risk of windthrow is a main constraint to low-impact silvicultural systems (LISS), and LISS is not usually an option on the windiest sites.
- Where LISS is inappropriate, use of more species within or between stands would help spread risk under a clearfell-restocking management system. Managing stands to maintain a more continuous and even canopy roughness will also help to reduce the risk of wind damage, as will early and more frequent thinning interventions.
- Work is required to expand site suitability knowledge and information for a wider range of species that may have a role in the future. Several alternative species for a warmer climate might be suitable for certain site types in Wales where native species are not required. These include: Monterey pine, southern beech (rauli and roble), coast redwood, walnut and some eucalyptus species. These could be mixed on suitable sites with 'known' species.
- It is important to balance the risk of climate-change impacts on current management systems against the risk associated with moving to a new and less well-tested system.

Site operations

- Management of forest operations on wet soils will become more challenging. In particular the management of water from wet sites to watercourses will need to address the likelihood of greater surface run-off. This will require a greater emphasis on good infrastructure management, both roading and tracking, and the need to increase the monitoring and maintenance of the existing infrastructure (e.g. drains and culverts).
- The 'window' for the late autumn planting of bare-root spruce and larch is likely to reduce, but there will be an extension of the planting season for containerised trees. The spring planting time for bare-root stock is likely to be curtailed on drought-prone eastern sites.
- There will be more weed competition on many sites. Careful assessments of site type and choice of weed control techniques will become critical in a less forgiving environment.

Adaptation: knowledge-transfer and planning

- Contingency plans must provide an adequate response to the potential increase in occurrence of: a) widespread windthrow from a severe storm, b) fire outbreaks and c) outbreaks of pests/disease.
- Challenges include the need to increase sector awareness and training.
- Organisations throughout the forestry sector must be adequately prepared for climate change. This will involve the use of monitoring systems to recognise change, reporting systems capable of effectively communicating change, and management systems that are able to respond and adapt, in order to cope with change.

Management of Priority woodland habitat

Five of the Priority woodland habitats (UKBAP) occur in Wales, and are considered in turn below. Native and semi-natural woodlands provide a core resource for the conservation of woodland biodiversity, particularly those on ancient woodland sites. Well-managed native woodlands may also provide an important resource of timber, non-timber forest products and locations for people to enjoy the natural and cultural environment and to enhance well-being. Native woodland communities are in a dynamic balance with climate and other factors; thus climate change is very likely to impact on species assemblages and the ecosystems associated with different woodland types. Climate change is also likely to:

- drive successional change leading to gradual changes in woodland type;
- increase natural disturbance, which will become a more prominent feature of Priority woodlands: wind, fire, and changes in pest ecology and disease epidemiology are likely to affect native woodland habitats as well as plantation forests;
- produce changes in the frequency of seed years for many broadleaved species leading to impacts on natural regeneration and changes in food abundance for seed eating species.

Upland oak woodland

- Upland oakwoods are widespread throughout Wales where they account for about half of the semi-natural woodland cover of Wales.
- Warmer and drier summers are likely to have an impact on epiphytes.
- Increased natural disturbance is likely to occur from winter gales which may break branches and blow over trees with inadequate root systems.

- Milder winters, springs and autumns will allow a wider range of broadleaved species to colonise (e.g. beech colonisation in Atlantic oakwoods).
- There is likely to be an increase in the frequency of disturbance from fire, particularly in oak woodland adjacent to heather moor and in woodlands popular with visitors.

Upland mixed ash woodlands

- Ashwoods occur on freely draining, but also on slowly percolating, fertile, alkaline and calcareous heavy soils. This type of woodland comprises about 25% of the semi-natural woodland area of Wales. In the west of Wales, as for oakwoods, more frequent natural disturbance events may occur, creating canopy openings with colonisation by a greater range of plants.
- Ash is very shade-tolerant as a seedling and young sapling, and can regenerate and compete successfully in the intense shade of dense woodland. Therefore, although tree-species composition may change in the warmer climate, this may happen more slowly in ashwoods than in other woodland types, even though the age structure may broaden in response to more frequent disturbance.

Wet woodlands

- Wet woodlands are dominated by species of alder, willow and birch, with the proportions being dependent on biophysical conditions including climatic warmth, soil wetness and fertility.
- Winter flooding is likely to become more frequent, and this will affect the lower floodplains of river systems.
- Some limited wet woodland colonisation might be expected on mires, fens, bogs and wet meadows.
- The projected changes are likely to maintain wet woodland in major valleys, with plentiful groundwater and a high water table from wetter winters. Wet woodlands in the lower reaches of major catchments are dependent on rainfall occurring in upland headwater tributaries.
- There is likely to be an increasing role for wet-woodland management in many river catchments, to help provide a natural defence against flooding.
- Riparian woodland can also help regulate extreme water temperature fluctuations, protecting fish populations from thermal stress.
- There is likely to be an increase in the colonisation of ash within alder woods, particularly in areas with drier summers in the east and south of Wales.

Lowland beech and yew woodlands

- Beechwoods are found on both light freely draining calcareous soils and neutral to slightly acid heavier soils with impeded drainage. The beech zone is restricted to south Wales, although its natural range may have extended further north if woodland fragmentation had not prevented its spread (Wesche *et al.*, 2006). Further spread to the north and west is therefore likely, driven in part by climate change.
- Mature beech trees are sensitive to drought and seasonally fluctuating water tables.
- Climate change will drive succession to other woodland types such as oak (especially pedunculate oak on heavier soils) or to scrubbier habitat depending on soil depth, soil water holding capacity and the change in rainfall seasonality.

Lowland mixed broadleaved woodland

- This woodland type occurs on heavier soils and often in association with upland ash woodlands. The frequency of natural disturbance through winter storm damage and summer drought is likely to increase, and woods may become scrubby where this occurs.
- Increased winds may do no more than reduce the number of older trees in woodlands on drier and sheltered sites, providing a deadwood resource.
- In a warmer climate, bramble growth may become more rank and more dominant.
- Fire damage may become more common, as many of these woodlands are used by people for recreation. Public access restrictions are likely to be needed in woodlands of high potential fire risk.
- Sycamore and beech colonisation is likely to increase in mixed broadleaved woodlands, as beech-seed viability will improve in a warmer climate and sycamore will out-compete oak, ash and elm.

Landscape-scale planning

- A considerable amount of Priority woodland habitat is fragmented. Some woodland expansion and a reduction in the intensity of land management between habitat patches of Priority woodland will help link woodland habitat at the landscape-scale. The development of habitat networks should help reduce fragmentation (Watts *et al.*, 2007), and will help increase the resilience of ecosystems to climate change (Fahrig, 2002).

Conclusion

Research into the impacts of climate change will continue, and further modifications and refinements of practice will result from new projections and information about likely impacts on forests. Future outputs from this research programme will be used in policy development and best practice guidance. In this way we will continue to adapt forestry practice to both ensure provision of ecosystem services and the maintenance of a strong, viable, sustainable and carbon-efficient forest industry. This will allow for the continued management of high quality woodlands and production of top quality woodland goods and services in Wales.

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FCRN301/FCW(CG)/CG-1K/JUL08

ISSN: 1756-5758
ISBN: 978-0-85538-764-8