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The potential effects of climate change for trees and woodland in the South West

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THE POTENTIAL EFFECTS OF CLIMATE CHANGE FOR TREES AND WOODLAND IN THE SOUTH WEST

Background

Woodland in the South West represents a significant resource, covering an area of 212 022 ha (9% land cover), with broadleaf and mixed woodland dominating; conifer woodland contributes less than 25% to total woodland cover. There is therefore a requirement for an assessment of the future effects of environmental change, both on the productivity of commercial forests and the implications for biodiversity in woodland, and also the health of urban and amenity woodland and street trees.

Global climate change

The climate, at both global and local scales has been changing at an unprecedented rate over the last 50 years. Global mean temperature has risen by 0.6^{o}C, rainfall patterns have changed, sea levels have risen and there has been an increase in the frequency of extreme events. It is widely believed that observed global warming and climate change is a result of the build-up of greenhouse gases, principally carbon dioxide, in the atmosphere. Excessive greenhouse gas emissions resulting from human activity are expected to continue, at least during the first decades of this century, leading to further forcing of the Earth's climate system with a global temperature rise of between 2 and 4.5^{o}C predicted by the end of the century.

Predicted climate change in the South West

Climate warming in the South West is predicted to be of similar magnitude to the global rise in temperature, but with warming slightly greater in summer than winter. The magnitude of change is predicted to vary little across the region, although the wide variation in existing climates will result in different impacts on woodland across the region. Winter rainfall will increase significantly, while summer rainfall is predicted to be half the 1961-90 average under some scenarios by the 2080s. The predicted increase in temperature, reduction in summer rainfall, together with a reduction of up to 10% in relative humidity will lead to summer droughts becoming increasingly sever and frequent. Snowfall will become an increasingly rare event, and by the 2080s under the high emissions scenario, to become non-existent. Cloud cover is predicted to show modest reductions in summer, possibly leading to a small increase in the diurnal temperature range. This modest reduction in cloud cover translates into a much larger increase in (direct) sunshine, such that a 43% increase is predicted under the 2080s High scenario. Although changes to wind speed and storm events are the least certain of the climate change predictions, there is an indication that the winter storm track will move southwards resulting in an increase in the number of deep depressions crossing the UK and a modest increase in average winter wind speed across the South West. The UKCIP02 scenarios for the grid-square centred on Dartmoor are summarised in Table 1.

Season	Winter				Summer			
Timeslice	2050s		2080s		2050s		2080s	
Emissions scenario	Low	High	Low	High	Low	High	Low	High
Tmean (°C)	+1.0	+1.6	+1.5	+2.8	+1.7	+2.7	+2.4	+4.7
Precipitation (%)	+7	+11	+11	+20	-19	-30	-27	-52
Snowfall (%)	-41	-64	-58	-100	-	-	-	-
Wind speed (%)	+1.8	+2.8	+2.5	+4.8	-1.8	-2.8	-2.5	-4.8
Soil moisture (%)	0	0	0	0	-15	-24	-22	-42
Relative humidity (%)*	-0.6	-1.0	-0.9	-1.7	-3.9	-6.2	-5.5	-10.7
Cloud cover (%)*	0	0	0	0	-5.3	-8.4	-7.5	-14.5

Table 1. Climate change predictions for the 50 km gridsquare centred on Dartmoor, based on the UKCIP02 scenarios. [*For relative humidity and cloud cover, predictions are expressed as absolute reductions or increases in current climate data (in units of %), and not as proportional changes to the variable.]

The direct effects of rising atmospheric carbon dioxide concentration

Outside of the role as the principal driver of climate change, the expected increase in the concentration of carbon dioxide in the atmosphere will have direct effects on tree physiology. Carbon dioxide fertilises photosynthesis, and model simulations together with controlled environment impact studies suggest that productivity increases of 2-4 yield classes (m^3 ha^{-1} yr^{-1}) should be anticipated. At the same time, elevated CO_2 levels lead to lower water use as a result of the leaf pores (stomata) closing which should, to some extent, counteract increased rates of water use that will result from the predicted rise in temperature. Other direct impacts of rising CO_2 levels include an increase in leaf area, a possible reduction in timber density and quality (generally ascribed to faster growth rates), a reduced risk of damage from insect herbivores as a result of a decline in the nutritional quality of foliage, a tendency towards an increased allocation of resources to the roots relative to the above-ground tissues and the development of nutrient deficiencies or imbalances, again as a result of more rapid growth.

Species suitability for commercial forestry

Model predictions obtained using the knowledge-based decision support system Ecological Site Classification (ESC) suggest that on the basis of the [1]UKCIP02 climate scenarios, the productivity of the most suitable species across most of the South West will increase. However, the identity of the most suitable or productive species (in commercial terms) in a given locality is likely to change. Sitka spruce will become less suitable at lower altitude, and particularly in the East. However, high productivity is maintained across much of the Peninsula (Devon and Cornwall), with an increase predicted under the 2050s Low scenario. Productivity of Scots pine is predicted to fall significantly across the whole of the region, but particularly in the East. This contrasts with the predictions for Corsican pine for which positive impacts of climate change are largest in the East. Douglas fir is predicted to become more suitable in the timber production areas of Devon, but to become less suitable to both the East and West. Larch shows little change in suitability over the timeframe assessed here. Of the commonly planted broadleaf species, beech, ash and sessile oak are predicted to give way to pedunculate oak as the most suitable species in much of the east of the region. Initially, ash

[1] UKCIP02 climate change scenarios, produced for the UK Climate Impacts Programme by the Tyndall and Hadley Centres, and funded by the Department for Environment, Food and Rural Affairs (Hulme *et al*., 2002).

replaces beech in Wiltshire, Somerset and Devon (under the 2050s Low scenario) and is then replaced by pedunculate oak under the 2050s High scenario. Sycamore is also predicted to suffer in the east of the region, but to maintain productivity in the West. Sweet chestnut is the one broadleaf species for which the productivity is predicted to rise, particularly in the East. Qualitative predictions of the effects of climate change in each of the main production forestry areas in the region are given in Table 2, with county mean yield classes given for each of four species in Table 3. A note of caution should be sounded here, since the model predictions only represent the coming 50 years, and the long term nature of the forestry industry requires that predictions are made beyond this time horizon for strategic planning purposes. The species suitability maps relevant to the coming 50 years should also be treated with extreme care, since many uncertainties are associated with them. However, the main conclusion that there are unlikely to be major changes to the species that can be grown commercially in the South West over the coming 50 years is valid, particularly since the predictions to some extent represent a worse case scenario as the beneficial effects of rising CO_2 concentrations on productivity are not included in this ESC-derived assessment. Although native woodland suitability is not related to commercial productivity, ESC-derived assessment of yield class can provide some indication of trends in the condition and suitability of the overstorey species, particularly where a species is predicted to suffer significantly as a result of climate change, as is the case with beech in the east of the region.

	CP	SP	DF	SS	POK	SOK	AS	BE	SY	SC	SBI	DBI
Cornwall	-	-	-	-	0	-	0	0	0	0	-	-
N Devon	+	-	+	+ -	0	-	0	-	0	0	-	-
Dartmoor	0	-	-	+ 0	0	-	+	0	0	0	-	-
Exeter+S Devon	0	-	+ -	-	-	-	0	-	-	-	-	-
N. Somerset	0	-	-	-	-	-	-	-	-	+	-	-
Ringwood+Wareham	0	-	-	-	-	-	-	-	-	0	-	-
Savernake	+	-	-	-	-	-	-	-	-	+	-	-
Dean	+	-	-	-	-	-	0	-	-	+	-	-

Table 2. Qualitative assessment of the impact of climate change on timber production for individual species, based on the Ecological Support System (ESC) decision support system. Information is provided for the principal timber producing areas for the 2050s. Where two responses are shown, the first represents the Low emissions scenario, and the latter, the High emissions scenario. -, + and 0 indicate negative, positive and no response, respectively. CP=Corsican pine; SP=Scots pine; DF=Douglas fir; SS=Sitka spruce; POK=pedunculate oak; SOK=sessile oak; AS=ash; BE=beech; SY=sycamore; SC=sweet chestnut; SBI=silver birch; DBI=downy birch.

	Percentage change in mean yield predicted for 2050s timeslice compared with 1961-90 baseline							
Species	**Ash**		**Beech**		**Douglas fir**		**Sitka spruce**	
Emissions scenario	**2050s Low**	**2050s High**	**2050s Low**	**2050s High**	**2050s Low**	**2050s High**	**2050s Low**	**2050s High**
Cornwall	2	2	-1	-5	9	7	2	-15
Devon	5	4	3	-4	11	8	4	-17
Dorset	-7	-17	-9	-28	0	-12	-23	-58
Somerset	-1	-12	-8	-25	-4	-15	-11	-43
Avon	12	-2	1	-19	11	-1	6	-33
Wiltshire	-1	-16	-12	-38	2	-15	-28	-69
Gloucestershire	4	-6	-3	-25	5	-7	-10	-53

Table 3. County mean yield class for four species under the 2050s Low and High emissions scenarios. Values are expressed as percentage change relative to the 1961-90 baseline, and were obtained using the Ecological Support System (ESC) decision support system.

Climate change and forest fires
Currently, the most damaging forest fires are in spring with dry brash and litter from the previous growing season fuelling the fires. Rainfall in spring is not predicted to change markedly, and the earlier growth of ground vegetation as a result of climatic warming could reduce the incidence of forest fires in spring and early summer. However, extended summer droughts such as those experienced in 1976 and 1995 result in a secondary fuel source in late summer as the ground vegetation dies and dries off. This is clearly demonstrated in fire statistics, which show peaks in years with extended summer droughts. The predictions of an increase in the frequency and severity of summer droughts would thus be expected to a large increase in the number of fires and area affected in those years.

Climate change, woodland biodiversity and suitability for native woodland
Although there are unlikely to be major changes in woodland type as a result of climate change, assessments of suitability for native woodland using ESC indicate that major changes to vegetation community structure based on the National Vegetation Classification (NVC), are likely. For example, the distribution of upland oak woodland (NVC W11) is predicted to contract significantly, and to be replaced by lowland oak woodland (NVC W10). Under the 2050s High emissions scenario, the climate of the entire South West is predicted to be unsuitable for W11 woodland. A range of responses will be evident across the range of native species associated with woodland, with some winners and some losers. The rate of change of the climate is predicted to be unprecedented and is likely to require management intervention to aid the migration of plant, mammal and invertebrate species. Larger areas of woodland, together with migration corridors and habitat networks and planned translocation of certain species are all options that would be beneficial towards adaptation to climate change. There is great uncertainty over the adaptive potential of local provenances, given the rate and scale of the climate change predictions. Although current research is demonstrating significant adaptive capacity in trees, the changes may nonetheless lead to increasing mortality. Non-local or non-native provenances could prove more suited to the future climate, although their use would have to be balanced against the requirement to maintain biodiversity in the form of the local genetic base. The distribution of native woodland fauna and flora will change, and model predictions of the effects of climate change are available for a range of species based on their current distribution across Europe. This may result in increasing mortality as climate change progresses, although on-going research is demonstrating a significant adaptive capacity. Non-local or non-native provenances would thus be an option for new plantings, which is contra to current policy. However, the use of non-local provenances needs to be balanced against the requirement to maintain biodiversity in the form of the local genetic base. The distribution of native woodland fauna and flora will change, and model predictions of the effects of climate change are available for a range of species based on their current distribution across Europe.

Climate change, habitat action plans and species action plans
The two UK priority woodland habitats are both classed as high priority in the South West. Lowland mixed broadleaf and lowland beech and yew would not be

expected to be significantly compromised by climate change in the short to medium-term. Growth of the overstorey tree species will be reduced in the east of the region, but be largely unaffected in the west. Yew may, however, suffer as its climatic range in the South West is predicted to contract by the 2050s under the High emissions scenario according to the SPECIES model used in the Monarch[2] project. Of the species covered by SAPs, the pearl-bordered fritillary and waved carpet moth are distributed across the south and west of the UK and thus climate change would not be expected to be a major driver to any change in distribution, as would also be the case for the widely distributed argent and sable moth. However, the requirement of both the pearl-bordered fritillary and argent and sable moth for moist woodland habitat may lead to an indirect climate-driven contraction of their ranges in the south west. The preference of the heath fritillary for hot, sunny hillsides in the South West suggests that climate change may be a positive driver for this species. Based on its current distribution, climate change would be expected to be a positive driver for the dormouse, as is also the case for the lime bark beetle on the basis of the climatic requirements of small leafed lime. Given the widespread distribution of the bullfinch, climate change would be expected to have little direct effect. The willow tit is predicted by the SPECIES model to lose all climate space in the South West under the 2050s High scenario, contrasting with the turtle dove, which is predicted to expand its range in the region.

ESC simulations predicts that the South West will become unsuitable for W11 upland oak woodland under its current definition. However, the majority of species which are the subject of SAPs would not be expected to be detrimentally affected by the direct effects of climate change, and with the high brown fritillary possibly benefiting. For both priority woodland habitats, woodland and landscape management is likely to have more impact on their constituent SAP species than climate change.

Impacts of changing wind speed

Although only a small increase is predicted in average winter wind speed, any increase has the potential to have negative impacts, particularly on upland forestry. In addition, the distribution of wind speeds is as, if not more, important as the average wind speed. Given the uncertainty in predictions of changes to wind speed and the occurrence of storms, predictions of their impact on forestry are still more open to conjecture. A preliminary analysis suggests that the DAMS wind hazard classification shows little change, although at higher altitude, both broadleaf and conifer woodland appear to become less suitable for timber production.

Impacts on water quantity

The interactions between woodland and the water resource are both positive and negative when viewed in the light of climate change predictions. In terms of quantity, this is because under the current climate, some types of woodland intercept and evaporate more rainfall than other land. In winter, the high interception losses of conifer woodland result in reduced effective rainfall (entering groundwater or watercourses). Where the upper reaches of catchments are

[2] Harrison PA, Berry PM and Dawson TP (Eds.) (2001). Climate change and Nature Conservation in Britain and Ireland: Modelling natural resource responses to climate change (the MONARCH project). UKCIP Technical Report, Oxford.

heavily wooded, evidence suggests that downstream peak flows can be reduced locally by up to 10%. Woodland also has the ability to increase infiltration rates into the groundwater, further mitigating the immediate effects of high winter rainfall by reducing peak flows. However, these positive effects may be counteracted by the presence of drainage channels and effects of felling in upland forests increasing peak flows, and current thinking is that the overall effect of upland forests on downstream flooding is neutral. Floodplain woodland has a potential role to play in flood alleviation by slowing down flood flows, while both floodplain and riparian woodland help to prevent erosion. Changes to land-use in response to both planning policy and climate change provide opportunities for an increase in floodplain and riparian woodland as an alternative land-use. The tolerance of individual species to prolonged inundation by freshwater is an important issue, given both the potential for floodplain woodland expansion and the likely increase in the frequency and severity of lowland flooding.

On the negative side, the increased use of water by woodland compared to other land-covers reduces catchment water yield in summer. On an annual basis, the limited information available indicates that water yield from broadleaf woodland is greater than that from conifer woodland. In comparison with pasture, water use of conifer woodland is significantly increased; evidence is more equivocal for broadleaf woodland, with studies on sandstone (oak) and chalk (beech), respectively, suggesting higher and lower water use compared to grass. Given the predictions of lower summer rainfall, increased evapo-transpiration, longer growing seasons and thus shorter recharge periods for groundwater reserves coupled with expected increases in demand, this role of woodland will come under further scrutiny and could become a significant problem. Detailed consideration of water use in forest design plans together with extensive consultation with other interested parties will need to become more prominent in the future, particularly given the opportunities and policies for promoting woodland expansion.

Coastal flooding
The current indicative estuarine and riverine floodplain maps provide an indication of those areas at risk from flooding. However, to date, the climate change scenarios have not been incorporated within the rainfall input data. In low lying areas, sea water flooding and saline incursion should be considered in WGS applications and the forest design plans. A review of the salt tolerance of individual species is available, and should be consulted in these instances.

Impacts on water quality
Because of its large leaf area and high level of turbulence compared with other land covers, woodland is efficient in trapping pollutants, and as a result, is implicated in acidification of watercourses, particularly in areas with high rainfall and on acid sensitive geologies. Interactions between woodland and surface water acidification are likely to be affected by climate change. Precise predictions cannot be given at this stage, but inferences based on the published climate change scenarios can be made. Possible negative interactions are that increased winter rainfall could potentially increase the deposition of pollutants in rainwater if recent observed reductions in pollutant emissions do not continue, while changing rainfall patterns could lead to short term episodes of pollution in watercourses. However, on balance current thinking is that climate change is unlikely to lead to significant

adverse effects on water quality resulting from atmospheric pollution. Dissolved organic carbon (DOC) levels have increased in recent years, and there is a suggestion that this is related to higher temperatures and, possibly, rising atmospheric carbon dioxide levels. Consequently, this aspect of water quality may be negatively impacted by climate change. Riparian woodland could have a role to play in providing shade and protecting fish stocks and invertebrate populations from excessive increases in temperature which would adversely affect them. A careful balance between shade and open space must be achieved, which is covered in current guidance.

Woodland, air pollution and climate change
Outside of the potential for woodland to interact with acid air pollution leading to acidification of the water resource in some areas, trees and woodland interact directly with pollutants. The direct impacts of acid deposition are likely to decline along with emissions of the principal pollutants NO_2 and SO_2. Although there are no direct links to climate change, eutrophication, largely as a result of ammonia uptake by woodland is likely to continue to be of concern. Ozone is a pollutant that is predicted to increase significantly, largely as a result of ongoing global emissions of oxides of nitrogen and volatile organic compounds. As well as having a direct impact on tree growth and increasing susceptibility to drought, trees can reduce concentrations of ozone and other pollutants, particularly in the urban environment, with corresponding benefits to human health. However some tree species emit significant amounts of VOCs which are associated with ozone production. Although their contribution is small compared to industrial emissions, there may be pressure to plant species that emit low quantities of these compounds in the urban environment.

Climate change and insect pests of woodland
Predicting changes to the impact of insect pest and disease outbreaks is difficult because of the fine balance between pest/pathogen, host tree and natural enemies. Of the current insect pests, the effects of climate change on populations of the green spruce aphid are probably of most concern because of the link between winter temperatures and the prevalence of the insect. Significant losses to Sitka spruce are likely, and alternative species may need to be considered in forest design plans. The activity of the pine weevil (*Hylobius*) may also increase with climatic warming, presenting problems at restock of conifer sites. Bark beetles are also likely to benefit from climatic warming, especially if this leads to stressed trees that are more vulnerable to attack. Shorter processing times (felling to milling) warrant consideration to prevent an increased prevalence of blue stain fungi. A recent outbreak of the great spruce bark beetle, *Dendroctonus micans*, in North Devon has been contained using the natural predator, *Rhizophagus grandis*. Continued monitoring and application of this successful treatment should be continued as the beetle is likely to benefit from climatic warming and an increased incidence of drought. The horse chestnut leaf miner (*Cameraria ohridella*) may, in the near future, present the most visible threat (although mortality does not generally result) with climate change implicated in its rapid spread across Europe. Other exotic pests of concern, both because of climate change and changes in global trade patterns are the Asian longhorn beetle, and the eight toothed and great spruce bark beetles (*Anoplophora glabripennis* and *Ips typographus*). The potential for the Asian longhorn beetle to cause serious damage to street trees in

the coastal fringe is of particular concern, and continued vigilance to identify incursions during the importation of timber and wood-based packaging. Recently, concerns have also been raised over the potential for the emerald ash borer to establish populations as has been the case in the northern USA, where it is has led to widespread mortality of north American ash. A warming climate is thought likely to benefit this potential pest.

Climate change and diseases of trees
There is some evidence that the activity of Fomes root and butt rot, an economically important disease of conifers, may be enhanced at higher temperatures. Moreover, the risk of infection is considered to be low in wet soils in high rainfall areas; thus a change to drier conditions, at least in summer, might warrant reassessment of some currently low risk areas. However, the predominantly acidic soils in the south west lower the risk of Fomes infection. *Brunchorstia* is likely to become less of a problem in the future, improving the condition of Scots pine, and allowing Corsican pine to be planted more widely, which may be important across much of the South West, given the predictions of an increasing frequency of summer drought and Corsican pine being the only species predicted to benefit from climate change. However, red-band needle blight which affects Corsican pine has now been identified in the South West, and its rapid spread has been linked to climatic warming. This disease may limit the suitability of Corsican pine in the future. The current serious problem in the South West of *Phytophthora* infections of alder in riparian woodland would be expected to become more serious if winter rainfall increases as flooding episodes, which allow the build-up of debris around the root collar, appear to promote infection. *Phytophthora* root infections generally may become more prevalent under climate change. In the case of the species of most current significance, *Phytophthora ramorum* (cause of ‘sudden oak death’ in California), too little is known about its behaviour in the UK to make predictions, although evidence suggests that the mild moist climate of the South West may promote infection.

Climate change and woodland mammals
Most mammalian pests of woodland will benefit from the milder winters that are predicted. In addition, earlier growth of ground vegetation will provide forage for herbivores, which is currently one limitation to population expansion. Populations of fallow, muntjac roe and red deer have all been expanding their range in recent years, and they are now becoming a serious pest in some areas. The effects of climate change on the requirement for the management of deer populations should therefore be kept under review. Populations of grey squirrels will benefit from climatic warming as it is susceptible to winter cold. Control of their numbers is likely to be an ongoing problem for woodland management, particularly in view of the damage caused to beech and sycamore. Rabbit populations are also likely to increase (in the absence of changes to the incidence of *Myxomatosis*) as they will benefit from reduced mortality in the predicted milder winters, while their numbers will be unaffected by hot, dry summers. Most mouse and vole species would be expected to be either unaffected or benefit from climate change based on their current European distributions, except for the yellow necked mouse. The distribution of the dormouse indicates that it would also benefit from climate change, but warmer winters could interfere with hibernation and lead to increased mortality if local populations cannot adapt. Populations of woodland carnivores are

dependent on the availability of prey, and their population density and distribution would not be expected to be affected directly by climate change.

The impact of climate change on urban woodland and street trees
It could be argued that urban woodland has already developed under climate change because temperatures in towns tend to be around 2^{o}C higher than rural areas – the ‘urban heat island’ effect. In addition, water supply is often restricted as a result of the built environment being designed to increase runoff, and soil structure being compromised to some extent in most instances. It is therefore likely that street trees and urban woodland will be the first to show negative impacts of climate change. Ongoing monitoring of non-woodland tree condition is therefore important. If deterioration of the condition of street trees becomes apparent, a conscious move towards more suitable species will need to be made.

Climate change and the benefits of urban trees and woodland
As already identified, urban woodland has a significant role to play in reducing air pollution, with particulates probably the most relevant in the urban environment. Although the effects may be small, evaporation from woodland and trees reduce water volume entering the urban drainage system in extreme rainfall events and therefore have the potential to reduce flash floods, which are predicted to become more commonplace. Evaporation from vegetation also provides cooling of the order of 1-2^{o}C relative to the built environment and thus has significant benefits in terms of comfort and financial benefits in terms of energy costs associated with air conditioning. Finally, the social and psychological benefits associated with woodland, particularly as climatic warming proceeds may be considerable. Expansion of urban woodland and the planting of suitable street trees should be considered as an adaptation to climate change.

Climate change and veteran trees
Although veteran trees have, by definition, survived a large range of climatic events and thus demonstrated great resilience to changing conditions, the threat posed by climate change is serious. Evidence of changing management such as the felling of adjacent trees or altered competition for water from grass leading to the death of veteran trees demonstrates the effect that a changing environment can have. Anecdotal evidence provides some indication of how climate change may affect veteran trees. Many large, mature or over-mature beech were lost immediately following the droughts of 1975/6, 1983/4, 1989/90 and 1995/6. Although oak was less severely affected, the widespread dieback to mature trees that occurred during the 1990s in the south east of England is thought to have been precipitated by, among other factors, the series of drought years in the 1970s and 1980s. Any effect of climate change on mycorrhizal associations may also affect the long-term survival of veteran trees. Observations also suggest that parkland trees are more severely affected than woodland trees, while it appears that ‘hulks’, in a state of reduced activity may be better able to withstand drought. Crown reduction may provide an adaptation to climate change in specific cases, but too little is known at present to provide any guidance.

Carbon sequestration
Woodland can play two principal roles in reducing net emissions of greenhouse gases (primarily carbon dioxide). Uptake of carbon dioxide in photosynthesis and

conversion to standing biomass is the most obvious role that woodland can play. In addition, an enhanced use of woodfuel and wood products can also reduce net carbon emissions by substituting for fossil fuels or materials with a high fossil fuel input required for their production. Voluntary carbon credit schemes may provide additional income for woodland owners and an incentive for woodland expansion but woodlands are not currently included in the official EU Emission Trading Scheme. It should be recognised that carbon storage in woodland is potentially reversible, either through management decisions, catastrophic storms, pest and disease outbreaks or the effects of climate change itself. Nonetheless, it may be argued that, on a global scale, sequestration of carbon through afforestation and woodland growth could provide 'a breathing space' for new technologies and a low carbon economy to be developed. Furthermore, any incentive for woodland expansion will provide the many other benefits of woodland, and additionally provide wood fibre for future generations. Carbon sequestration in woodland is finite, and therefore fossil fuel emissions cannot continue to be offset by woodland expansion and growth. In contrast, the utilisation of wood and wood products to substitute for fossil fuels allows the avoidance of fossil fuel emissions to continue long after the woodland itself has ceased to sequester carbon. Wood fibre can substitute for fossil fuels directly as bioenergy (see separate section) or, indirectly, by replacing materials with high fossil fuel consumption associated with their production. The development of the wood and wood products industry is therefore a key factor in maximising the carbon benefits of woodland.

Bioenergy

The utilisation of both forest residues and purpose grown short rotation coppice in bioenergy plants can make a significant contribution to the requirement for an increase in renewable energy. Where thinnings and forest residues are used, careful consideration needs to be made of the implications for long-term site sustainability. The commercial growing of short rotation poplar and willow coppice for bioenergy may prove a popular alternative for ex-agricultural land. However, the development of a market that suits both growers and biomass plant operators can prove difficult as evidenced by Project Arbre in Yorkshire. As is also the case with the use of forest residues for bioenergy production careful consideration of the transport chain is necessary to ensure that a net reduction of fossil fuel emissions is achieved when poplar or willow coppice are used as biofuel. Bark, chips and sawdust from sawmills also represent a potential source of biofuel.

Climate change indicators

A small number of climate change indicators relevant to woodland and forestry are available or could be developed. Available indices include crown density and aphid damage to Sitka spruce, and mast (seeding) intensity in beech and oak, both of which are currently recorded in the annual FC forest condition survey with data available from 1987. Leafing dates and other phenological observations could provide good indicators, using amateur observers under the auspices of organisations such as the UK Phenology Network. However, these indicators would suffer from a lack of baseline data for sites in the South West. It is clear that growth rates or forest productivity would not provide a good indicator as a result of the large number of contributing factors. An alternative approach would be to select species which would be expected to be affected by climate change on the basis of model outputs. This approach would also suffer from the lack of baseline data, but could provide a powerful indicator for the future. Links between the performance of individual species and climate change should not be rejected purely on the basis of not having good baseline data.

Conclusions
Predicted climate change is likely to result in increased tree growth rates and woodland productivity over the next 50 years for much of the South West region, irrespective of whether the course of climate change is closer to the Low or High scenarios given in the UKCIP02 climate change scenarios. However, model predictions indicate large differences within the region. For Cornwall and Devon, climatic warming, rising atmospheric CO_2 levels and relatively high rainfall are likely to result in the increasing productivity alluded to above. In contrast, in the east of the region particularly Dorset and Wiltshire, the positive effects of rising atmospheric CO_2 levels may be countered by an increased incidence of drought. For some species including beech and Scots pine, significant yield reductions are likely, particularly on some of the more free-draining soils. The assessments given here would be invalidated if climate change falls outside the envelope of those scenarios or in the unlikely event of an abrupt change to the Gulf Stream and a cooling of the climate of the north west Atlantic. It should also be noted that these assessments are made on the basis of predictions for the next 50 years. As some management decisions have implications for periods in excess of 100 years, longer term assessments should be made in some instances, with an anticipation that the most extreme of the UKCIP02 scenarios given here may represent the lower end of predictions over an extended time period. Forest design plans, and species choice for restocking or new woodland planting should take account of the climate change predictions, under the general premise that the climate will become hotter and drier. Species already at the drier end of their range for a given site should not be considered for commercial timber production. Alternative species including sweet chestnut, walnut, *Robinia*, *Nothofagus*, Radiata pine and Pinaster pine also warrant consideration, particularly since problems in the past associated with frost susceptibility are unlikely to be as significant in the future.

Although productivity is expected to increase, these predictions may be tempered by extreme events including catastrophic storms, severe droughts and unforeseen insect pest or pathogen outbreaks. Clearly, water will become an increasing important and controversial resource, with the role of woodland in both flood amelioration and water yield requiring careful consideration at a landscape level. Although major native woodland types are unlikely to be at risk in the South West, with the possible exception of W11 upland oak, there will be changes to some of the vegetation communities comprising the current classification of native woodland, and a debate over NVC woodland types should be welcomed. Some native species and habitats will respond positively to climate change, while others will suffer. Impacts on biodiversity are inevitable, but planning and land management could aid adaptation through providing migration corridors, suitable reception habitats and refuges. Urban woodland and street trees may be the first to show any detrimental effects of climate change as they currently exist in a challenging environment. The landscaping industry needs to be made aware of the implications of climate change, and to adapt practices to the predictions.

Woodland also has a positive role to play in climate change mitigation through storing and sequestering carbon and also the avoidance of fossil fuel emissions through the utilisation of forest residues and short rotation coppice in bioenergy projects. Although climate change may have some detrimental effects, adaptation is possible and there will be opportunities for woodland and forestry as alternative land covers. Land management and integrated land-use decision making will be become increasingly important as climate change proceeds.