SECTION 4

ADAPTATION

Chapter 9 - The adaptation of UK forests and woodlands to climate change

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THE ADAPTATION OF UK FORESTS AND WOODLANDS TO CLIMATE CHANGE

Chapter 9

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Key Findings

There is considerable uncertainty about how trees, woods and forests will respond to climate change, but change they will. New cultural landscapes will develop in response to the new conditions that are not simple transpositions of those that currently occur at lower elevations, or further south in Europe or that have occurred under warm periods in the past. Indirect responses as consequence of changes in other land management/policy will be as important as direct impacts.

Action to start to change the extent, composition and structure of our woodland is needed in order to avoid future serious limitation of goods and services from our forests and potentially also wildlife losses. A move towards planned rather than reactive adaptation is desirable, given the long response rates of trees and forests. We need to increase the resistance and resilience of existing woodland. Within existing woods an overall increase in management intervention is likely to be needed, even in semi-natural woodland, to modify the biological and ecological response of forests to climate change in order to maintain and increase benefits to society. This will be a challenge as much broadleaved woodland is currently unmanaged, costs of management can be high and owners may require professional advice and support. A proportion of woods should however, be left as minimum intervention areas, in order to assess the degree of 'passive adaptation'.

The majority of woods are likely to be treated as high forest in different forms. Whereas clearfell systems have predominated in the past, in future continuous cover forestry approaches may become more advantageous, because they are thought to be more wind-firm; maintain a more even carbon storage; show lower soil carbon losses during harvesting; and maintain higher humidity levels. However, the evidence that they will deliver these benefits needs strengthening. There may be less need for coppice systems to maintain southern or thermophilic elements of the woodland system, although coppice may still be desirable for light-demanding species and young regrowth for bird species needing dense shrub layers. The silvicultural system *per se* is however, less important than the structures that it creates and their resilience and robustness in relation to climate change.

Adaptation measures on the ground need to be set in clear national and regional frameworks, and based upon regular updating of the climate change projections and their specific implications for forests and trees. There needs to be ongoing iteration between:

- national targets and aspirations, reflected in forestry strategies and other guidance;
- regional and other sub-country level frameworks that indicate the priorities for different types of forestry activity and the balance between forestry and other land use;
- local projects and regulation which determine what work actually goes ahead.

Practical adaptation measures need to be tailored to the different types of woods, woodland owners and their objectives.

Adaptation will involve increasing the tree and woodland cover to develop new habitat networks for biodiversity and for other purposes. New afforestation must be developed sensitively with full recognition of the potential implications for biodiversity, agriculture, water harvesting, housing and infrastructure development, alongside the other associated costs and benefits.

In order to continue to meet demands for timber, fuel, and some ecosystem services, we may need to introduce new provenances and new species, although research is needed to establish which are fit for purpose and likely to survive. The nature conservation community needs to be clearer as to:

- what it is trying to conserve in a changing environment;
- whether the past emphasis on use of native species and local provenances is still valid;
- where might species and provenances from the near continent be better suited to future conditions, or provide refuge for rare and threatened species.

Many social values of woodland are related to how accessible they are. In future, increased emphasis may be placed on accessibility without reliance on cars, and hence on the benefits of urban and peri-urban woodland. There will also be a need to help people understand the changed appearance of some landscapes.

There must be adequate monitoring of forest and woodland states and processes to assess and adjust the use of adaptive management; improved decision-making processes will be needed to cope with the assessment of risk, and the inherent uncertainties.

In this chapter, we consider the adaptation of the UK's tree and woodland cover to make it more resilient to climate change over the next 50–100 years. Resilience implies that the future tree and woodland cover recovers quickly from climate change impacts and the ecosystem services provided are maintained across the landscape.

The UK woodland resource is frequently split into semi-natural stands and plantations, ancient and recent woodland (Spencer and Kirby, 1992; Goldberg *et al.*, 2007). All are within the scope of this chapter. These distinctions have underpinned forestry policy in the recent past, but may become less useful and clear-cut in the longer term, for example as species' distributions change and, if production forests are managed more as mixed species stands with varied structure, as they are re-stocked by natural regeneration ('close to nature' forests, see Chapter 6, Forest Management Alternative, FMA2).

9.1 What is 'an adapted forest cover' for the UK?

An adapted forest cover is one that is resilient under changing environmental conditions and continues to meet society's needs for goods and services. Adaptation results first from the biological and ecological response of trees and woods to changes in their environment (Lindner *et al.*, 2008). Forests adapt as the environment changes the presence or absence of species and their abundance. There can be longer term changes as species themselves adapt to new environmental pressures.

In the past, forests and trees have responded to climate change through changes in their range and distribution. In the post-glacial period, the British landscape went from tundra to pine–birch forests, to mainly mixed broadleaved forests (Godwin, 1975). However, there may be lags in species movement into areas that have become environmentally suitable (Svenning and Skov, 2005, 2007); mature trees may survive in an area long after the conditions for regeneration have ceased to be suitable, for example the small-leaved lime in northern England (Pigott and Huntley, 1981). The current composition may be limited by past environmental or historical factors: the English Channel appears to have limited the spread to Britain of some species common on the near Continent. Under conditions of rapid environmental change, the biological response does not necessarily produce forests that are optimally matched to the current environment.

Biological and ecological adaptation to climate change alone may not produce the kinds of woods and forests that society wants. Our needs and demands are likely to include the provision (Defra, 2007; Forestry Commission, 2001; Forest Service, 2006; Scottish Executive, 2006) of:

- carbon sequestration
- conservation of biodiversity
- environmental services such as soil and water protection, improvement of air quality
- forest products such as timber, fuel
- employment in forestry and forest-related industries
- recreation, attractive landscapes, cultural and historic features, and other contributions to people's quality of life.

In the UK, with limited land area and substantial human population, there are no significant moves towards major zonation of woodland for a single use. While the balance of services provided may vary, both nationally and between individual woods, the majority of woodland is likely to have to provide a range of services (Hunter, 1999).

Adaptation measures are often easier to implement in managed forests such as plantations than in natural forests (Nabuurs *et al.,* 2007) because the tree species composition and forest structure are more under managerial control (European Commission, 2007). An increase in management intervention is therefore likely, even in semi-natural woodland, to modify the biological response of forests to climate change, and in order to maintain benefits to society. Reductions in the risk of detrimental changes, such as loss of productivity, woodland cover, or species richness will also be dependent on management intervention. Management should not be aimed at adaptation to some specific, predicted climate regime, but towards developing the forest's capacity for adaptation to continuing climate change. There should also be a suite of minimum-intervention forests where natural processes predominate (Peterken, 2000); understanding what happens in the absence of intervention is a valuable guide to management elsewhere.

Vegetation dominated by long-lived species may be more vulnerable to increasing climate variability (Notaro, 2008). However, the long life of some forest species means that they may be relatively tolerant of wide variations in annual weather conditions. For example, some veteran oak trees in Windsor Great Park started their growth in the Little Ice Age (17th century), but have survived, so far, the increasing frequency of hot summers. The projected future climate impacts on trees and woods as they are now, need to be balanced against the risks from trying to change our trees and woods to meet the projected future climate conditions. Introducing species more tolerant of the expected higher summer temperatures in 2050, may not be worthwhile if they cannot tolerate current winter temperatures or late spring frosts (see also Chapters 4 and 5).

The current age distribution of our trees strongly influences their future potential to provide both timber and biodiversity. The conifer crops to be harvested in 2050 and the mature broadleaf stands in the second half of the 21st century will be largely those that are already growing – their area cannot be increased. The level of wood fibre production after 2050 will depend on how existing crops are managed, but also on how much new productive woodland is created between now and then. The future area of ancient woodland and the numbers of veteran trees are also largely constrained by what exists now, although other aspects can be influenced by the management approach adopted. The extent of open space and young growth in ancient semi-natural woods over the next 50 years will depend largely on active management. Thereafter, natural processes may create gaps more regularly as the current stands (mostly around 60–90 years old) start to mature (Hopkins and Kirby, 2007; Kirby *et al.,* 2005). Whether the broadleaved woods being created now are of timber quality when they are mature will depend on how they are treated over the next century.

Adaptation measures over the next two decades are needed to avoid future bottlenecks in the provision of goods and services from our forests and potential wildlife losses. While some adaptation measures cannot have much impact on our tree and forest cover for some decades, if we do not take action now, then much greater efforts will be needed subsequently.

9.2 Developing adaptation strategies and actions for UK forests

Several principles and priorities for climate change adaptation have been suggested, both in general terms and specifically for forest and tree cover (Mitchell *et al.,* 2007; Hopkins *et al.,* 2007; Smithers *et al.,* 2008; Nabuurs *et al.,* 2007; Millar *et al.,* 2007; Lindner *et al.,* 2008; Forestry Commission (a), in press). They can be summarised as: creating resistance and promoting resilience to change (see below); monitoring change and accepting landscape change.

Creating resistance to change. The longer that the current tree and woodland cover can be maintained as productive forests or rich wildlife sites, the more time that there is for other adaptation measures to be brought in.

- Resistance to change can be improved by reducing the impacts of other stressors on the systems, such as pests and diseases, pollutants, over-grazing and development pressures. Reducing deer pressure in woods, for example, allows more flowering and seed setting of species such as primroses, so increasing the potential for populations to survive drought years (Rackham, 1999).
- Management practices, such as rotation length, coupe size, tree species composition and canopy cover can be modified to favour retention of current production, habitat conditions, features or species (Humphrey, 2005).
- Resistance is likely to be higher in large blocks of woodland because they contain more internal variety of structure and are less affected by adverse edge effects, for example increased water loss or spray drift from adjacent farmland (Herbst *et al.,* 2007; Gove *et al.,* 2007); species populations within them tend to be larger and hence less susceptible to random extinction.
- Sites, species and features most vulnerable to threat need to be identified, as has been suggested for different groups of plants (Gran Canaria Group, 2006).
- Potential refugia need to be identified where the direct impacts of climate change may be less than in the surrounding region. Gorge oakwoods in north Wales may provide refuges for Atlantic bryophytes, sensitive to reduced humidity, as they appear to have done when much of the rest of the woodland was actively managed as coppice (Edwards, 1986).

Resistance is unlikely to be absolute however, and once critical thresholds are passed, change may be rapid and catastrophic.

Promoting resilience to change. We should seek to adapt the current tree and woodland extent, location, structure and composition towards those that will be more suitable for future conditions. For example, because of disease risks, alternatives to Corsican pine should be encouraged, where previously it was the favoured productive species.

Measures that have been suggested to increase resilience include:

- contingency planning for outbreaks of new pests or major new disturbance regimes (e.g. increased fire risk);
- encouraging a variety of species that can occupy the same functional space within the forest ecosystem, as has happened naturally at Lady Park Wood (Peterken and Mountford, 2005);
- increasing regeneration rate to allow more potential for selective pressures to work on seedlings;
- greater diversity of planting material, both at the species and population genetic level.

A disadvantage of higher resilience is that, much of the time, delivery of services from the forest may be sub-optimal. Economic analysis techniques are needed to judge the relative costs and benefits of occasional catastrophic losses of services versus regular, but sub-optimal delivery.

Monitoring both the processes taking place and the outcomes in order to:

- track whether climate change and its impacts are as expected;
- identify where and what forms of adaptation are successful or unsuccessful, as the case may be;
- provide a context that allows appropriate responses to rare, catastrophic events such as the 1987 storm or emerging issues such as ‘acute oak decline’ syndrome;
- validate models of species and ecosystem responses to climate change (e.g. Berry *et al.,* 2002; Sykes *et al.,* 1996; Giesecke *et al.,* 2007; Thuiller *et al.,* 2002), in order to improve future projections.

However, it can be difficult to separate the climate signal from other changes affecting monitoring results (Kirby *et al.,* 2005).

Accepting that new cultural landscapes will develop in response to the new climate conditions: The forests that develop over the next century will not be simple transpositions of those that currently occur further south in Europe (or at lower elevations), nor will they necessarily be like those that have occurred under similar climates in the past. Non-analogous assemblages (Huntley 1990; Keith *et al.,* in press) will form because:

- the new climates are not the same as those currently in southern Europe, for example there may be changes in storm frequency or severity;
- the 'starting point' (including the impact of landscape history on the composition and distribution of our forests) is different to that which led to the evolution of the southern European landscape;
- species respond individually to climate change, not as assemblages or communities (e.g. Berry *et al.,* 2002; Kirby *et al.,* 2005; Hill *et al.,* 1999);
- species distributions are affected by other factors (rates of spread, competition between species, herbivory, predation and facilitation) that interact with the direct climate impact (e.g. Svenning and Skov, 2005; Beale *et al.,* 2008).

BOX 9.1 Mediterranean treescapes in southern England?

In Spain, holm oak (*Quercus ilex*) is spreading to higher elevations, replacing heather and beech woodland (Penuelas and Boada, 2003). By analogy, on south-facing slopes in southern England, the vegetation may develop a 'Mediterranean' character. Possible adaptation responses might be:

- pines become more important for conifer production than firs and spruces (subject to diseases such as red band needle blight);
- walnut and sweet chestnut are favoured for broadleaved production;
- more need to plan for fire because of hotter conditions but also more open grassy woods;
- increased value placed on shade trees in rural and urban settings;
- active management for some open-space species is less important because they depend less on open areas providing warm microclimates;
- maintenance of shade and internal woodland humidity becomes more important;
- acceptance of southern tree species, e.g. holm oak, that are already established locally as part of our future wildlife.

9.3 National level challenges

9.3.1 Shifts in major forest zones

Much of the country is likely to remain within the broad temperate forest zone (Lindner *et al.,* 2008), although opportunities for Mediterranean-type species will increase and boreal species may come under more stress (see Boxes 9.1 and 9.2). Temperate broadleaved woodland may change its detailed composition and structure but retain a similar overall appearance (see Box 9.3). There may be shifts in which climatic factors limit particular species distributions. For example, hyper-Atlantic bryophytes (Ratcliffe, 1968) at the southern and eastern edges of their range may decline because of hotter summers, but in the north this effect may be offset by increased winter rainfall. Small-leaved lime regeneration may increase because of hotter summers, leading to infilling of its distribution in the south, but range expansion in the north (Pigott and Huntley, 1981). While it is possible to suggest possible adaptation measures, their application in practice will depend on an assessment of the benefits and costs that will accrue on any individual site.

9.3.2 Movement of individual species

The rate at which woods and forests adapt depends on species' ability to track climate change either by moving northward, or upward, or on to cooler or wetter aspects (such as north-facing slopes). Some species spread rapidly, such as grey squirrels, deer species or rosebay willowherb. Rapid spread also occurs through human assistance: trees planted outside their past natural range, the deliberate and accidental spread of species (including diseases) on cars, boots, among logs or other plant or soil material moved about the country.

For other species, the potential for movement to keep ahead of climate change is uncertain. Barriers to species colonisation, such as the English Channel, or the availability of suitable sites or soils and associated species within the preferred climate zone may slow the response to climate change. For example, the climate space for nuthatch (*Sitta europaea*) may increase to the north and west (Harrison *et al.,* 2001), but the availability of habitat in the form of old trees and behavioural factors, such as the perceptual

BOX 9.2 Future shifts in boreal forests?

The boreal forests in Britain are in the more mountainous regions so there is potential for some movement of forest upwards, widely reported elsewhere (Hawkins *et al.,* 2008), as well as to the north east, as has occurred in the past (Gear and Huntley, 1991). At lower altitudes, broadleaved trees may spread into pine woodland. Some boreal forest species are potentially sensitive to climate change, e.g. capercaillie (Harrison *et al.,* 2001), although forest management and predation may be more immediately critical. Possible adaptation responses include:

- review of where the natural elevation and latitude limits are for growth of different trees;
- assess potential impact of emerging pests and pathogens (e.g. the impact of red band needle blight on native pine);
- reduce deer browsing, which is limiting forest spread both altitudinally and latitudinally;
- accept changing composition of southern or lower altitude native pine stands through spread of broadleaved species;
- review the implications of forest spread for montane and northern open habitat assemblages.

threshold at which a bird is willing to disperse to a distant wood (Alderman *et al.,* 2004) may restrict its actual spread. Failure of species to spread into newly available climate space, for whatever reason, may allow the existing species to survive longer in sub-optimal climate space.

As species disperse in response to climate change, they must establish in competition with existing ones. Animal communities typically respond quickly to environmental change: there can be rapid taxonomic turnover and ecological rearrangement of the fauna (Wing and Harrington, 2001). However, fossil evidence suggests that plant communities may exhibit considerable 'inertia': pre-existing vegetation has a competitive advantage over new arrivals because it can monopolise resources and shade out invaders. There is typically a substantial time-lag between the arrival of new species and any significant change in the structure and composition of vegetation. This type of two-phase sequence of invasion was exhibited by Eastern hemlock (*Tsuga canadensis* (L.) Carrière) over the last 2500 years in Wisconsin (Parshall, 2002). Community inertia may also explain why beech, which seems to have been present in England since around 9000 BP (Rackham, 2003), did not become abundant in the pollen record until about 3000 years ago. Extreme events such as droughts or fire, which cause significant mortality, may trigger community turnover.

Modelling of species spread from southern European refugia in the current post-glacial period suggests that rates of 50–100 m per year are needed to explain current distributions of some major tree species, but some trees appear not to occupy their full climatic range (Svenning and Skov, 2005, 2007). However, Banuelos *et al.,* 2004 considered that the eastern range edge of holly in Denmark has shifted about 100 km within half a century (2000 m per year), possibly due to increasingly mild winter temperatures; a recent study of tree-line shifts in north America suggests tree migration rates of 100 km a century (1000 m per year) (Woodall *et al.,* 2009). Estimates for some herbaceous plants and invertebrates are much lower, only a few metres a year (Rackham, 2003). However, unless there have been significant changes in their dispersal ability over the last two millennia, there must be alternative 'rare long-distance' mechanisms that enabled them to reach Britain. For example, wild boar may be significant as dispersers of seeds of ancient woodland indicators on their coats or feet (Schmidt *et al.,* 2004). For some poor dispersers, there is a case for direct translocation as a human analogue of such rare long-distance dispersal events. Translocations within range are already a target in some Species Action Plans (DoE, 1995).

The adaptation strategy needs to consider:

- For how long should current species be maintained at the expense of allowing species of the future to establish and spread?
- Where is it appropriate to assist the dispersal process through active and deliberate human intervention and on what scale?

9.3.3 Interaction with other land uses

Any change in woodland cover to increase the supply of ecosystem services will not occur uniformly across the country and will be the product of interaction with other land-use policies and management choices. Historically, woodland remained abundant where there were reasonably close markets for the products (e.g. peri-urban forests or close to sources of iron); the expansion during the 20th century focused on land of little value for modern farming (Rackham, 2003; Smout, 2003). These produced

BOX 9.3 Re-sorting of temperate broadleaved woodland types

Across much of the UK, there are likely to be shifts in the main tree species. Oak was often favoured in planting programmes, where ash was the more natural dominant. Current trends are for ash to re-assert itself. Minor trees typical of southern and more continental woods may increase, for example lime and field maple; there may be an increased mixed deciduous component in woods formerly dominated by beech in the south, whereas beech may continue to spread into oakwoods in the north and west. In the uplands, oak and birch may grow and regenerate more vigorously at higher altitudes, as at Wistman's Wood on Dartmoor over the last century (Proctor *et al.,* 1980). In floodplains and other wet situations, changes in the water regime may favour or act against alders and willows. Shifts in the distribution and abundance of associated flora and fauna will occur, in part directly from climate change, but also influenced by management in and around the woods (Flemming and Svenning, 2004; Mitchell *et al.,* 2007).

Possible adaptation responses include:

- reassessment of productive potential of broadleaved species
- review of impact of emerging pests and pathogens, e.g. gypsy moth, acute oak decline
- accept changing distributions and assemblages of trees in broadleaved woods including near-continental species as part of future wildlife
- review the balance of management in woodland; there may be less need for coppice systems to maintain southern/thermophilic species, although coppice may still be desirable for light-demanding species and for birds needing dense shrub layers
- accept expansion of oak and birch woodland to higher altitudes than commonly found at present, assuming reductions on grazing pressures allow this to happen
- accept changing field layer compositions and associated faunal changes
- review the balance of open and wooded landscapes in both upland and lowlands.

Wood-pasture and parkland

The UK is believed to have a particularly high density of veteran trees, often associated with wood-pasture and parkland. These trees are increasingly vulnerable to extreme drought and storms, new or invigorated pests and pathogens, and their loss would cause loss of associated saproxylic invertebrates, lichens and fungi. Possible adaptation responses include:

- continued management of the individual trees to prolong their life
- establishment of new generations of trees where these are currently lacking
- speeding up development of 'veteran tree' features to allow colonisation of younger trees by specialist species
- precaution against increased fire risk (often these trees are surrounded by grass and bracken)
- the development of new open-grown trees in fields, hedges and other locations to spread the future overall population and distribution of veteran trees.

a heterogeneous woodland cover with distinct well- and poorly-wooded regions (e.g. Spencer and Kirby, 1992; Forestry Commission, 2003). Similar pressures will shape future land-use patterns.

Agriculture will remain the priority land use in the 21st century, because of increasing concerns about food security. There may be pressure to convert forests to farming (as is happening in New Zealand; Stevenson and Mason, 2008), where woodland occupies land seen as particularly productive. New opportunities for forests may emerge on sites that are too drought prone for un-irrigated farming, too wet in winter on floodplains or poorly drained soils; too degraded/polluted for economical food production (urban brown-field sites), or too remote. Local demand for wood or fuel may shift the balance towards clusters of woods around new markets; but conversely, there is pressure locally to clear forests to restore open habitats such as heathland or bog for biodiversity reasons (Forestry Commission Scotland, 2009; Forestry Commission, 2009). The carbon-sequestration consequences and sustainability of such decisions will be increasingly critical.

The role of woodland in regulating water flows will become more important, favouring development of increased woodland cover in upper catchments (except those on peat soils because of concerns about net carbon loss) (Nisbet and Broadmeadow, 2004; IFRMRC, 2008; Woodland Trust, 2008; see also Chapter 10). Large-scale woodland expansion may, however, not be suitable where water yields are already low and trees would have higher evapotranspiration rates than current crops.

Trees and woodland around settlements and cities are likely to be encouraged as improving quality of life (shade and shelter may reduce costs of air conditioning and heating), for recreation, and to a lesser extent as sources of local wood products (Britt and Johnston, 2008; developed further in Chapter 10). The numerous trees outside woodland in rural areas (Forestry Commission, 2003) may increase in value as shade for livestock. However, non-woodland trees can be more vulnerable to climate change because of their exposed situation.

There will be continued pressure on land for urban and infrastructure development that will impact on trees and forests, although these may trigger changes to planning guidance (e.g. in England Planning Policy Statement 9; ODPM, 2005) that may help reduce direct loss and increase compensatory planting where losses do occur.

A more integrated approach to land use is highly desirable since many ecosystem service flows depend on the interaction between wooded and open elements of the landscape. New combinations of land use, for example, agro forestry (Morgan-Davies *et al.,* 2007) or re-wilded areas (www.wildland-network.org.uk; Taylor 2005) may further blur past distinctions between forest and open land.

The above pressures and priorities need to be translated into new woodland or improved woodland management on the ground, through iteration between:

- national targets and aspirations, reflected in, for example, national forestry strategies (e.g. Scottish Executive, 2006), other guidance (e.g. Planning Policy Statement 9 in England emphasises the need for woodland protection), and Biodiversity Action Plan targets;
- regional and other sub-country level frameworks that indicate where the priorities for different types of forestry activity lie;
- local projects and regulation which determine what work actually goes ahead.

9.4 Regional and landscape-level adaptation

'Adaptation' measures may need to be different in southeast England from those in northwest Scotland, because the landscapes, the woods, and what is expected of them differ. Adaptation recommendations for managers have been made for woods in different parts of the UK (Ray, 2008a,b; Broadmeadow, 2002a,b). Similar attempts have been made to apply the biodiversity adaptation principles for England (Hopkins *et al.,* 2007; Smithers *et al.,* 2008) to local levels (Natural England, 2009). However, even within a single landscape, the critical factors may vary: changes in winter rainfall might be important for valley bottoms, whereas summer drought could be critical on adjacent south-facing slopes. In Catalonia, Jump *et al.,* (2006) found that beech growth was more limited by drought at the species' southern limits, but not where it occurred at higher altitudes. A priority for future research is identifying the extent to which it is possible and useful to refine impact and response data to sub-national levels.

At the regional level, the coupling between forests and land-use management and the local markets for forest products need to be planned in an integrated manner. This may be key for the success of forest adaptation. For instance, the development of large heating units based on wood chips or pellets, e.g. in schools, hospitals and other public buildings, should be coupled to the development of adequate management of woodlands and woodland creation in their vicinity. This guarantees the sustainable supply of wood at low transport cost to the combined heat and power (CHP) unit and secures a market for local forestry. It may also lead to greater social acceptability of intensive forestry alternatives.

9.4.1 Woodland products

Timber and wood products are traded globally, but for certain types of product and producer adaptation at the sub-national level may still be important to provide the right type, age and size of material locally. There needs to sufficient 'available' woodland to ensure long-term supply of raw material within economic transport distance. The resource must be accessible with no significant conflicts with other objectives that would limit its use. Mechanisms for linking small producers with local markets need to be better developed, for example the web-based service initiated by the Sylva Foundation (www.myforest.org.uk).

A more balanced age range across the landscape would ensure that there is consistency of supply year-to-year; at present there is often an imbalance in age classes because of periods of high exploitation (such as the two World Wars), followed by neglect and subsequent peaks of woodland creation (Forestry Commission, 2003; Mason, 2007). The wood produced should be of a size and quality suitable for a range of products. Historically, markets have often changed during the course of a rotation (particularly for slower-growing broadleaves), as exemplified by the decline in ship-building timbers, the rise and fall of mining timber, or of poplar for matchwood. However, quality and uniformity of product tend to be valued across a range of different uses. In addition, the size and distribution of stands for harvesting should be such that this can be done efficiently. The trend in the 20th century was towards large-scale harvesting, but a shift towards smaller-scale working, such as the promotion of continuous cover forestry in state forests in Wales, would have implications for harvesting technology and practice (for more detailed consideration of forest products see Chapter 7).

9.4.2 Biodiversity

The characteristics of landscapes which will retain or develop high biodiversity under climate change have been summarised by Hopkins *et al.,* (2007). They include:

- variation in topography, particularly slope, aspect and height. Lenoir *et al.,* (2008) report an upward shift in the optimum elevation of forest plant species by around 29 m per decade;
- diversity in soils and water regimes;
- numerous semi-natural land-cover types, which may provide the conditions that will allow a wide range of species to move through the landscape (Watts *et al.,* 2007; Watts, 2006);
- diverse and structurally-varied vegetation.

The underlying robustness derived from topography, soil or water regimes, can be modelled if the above is true: for example, biodiversity in Snowdonia should be more robust than that in the East Anglian plain under climate change scenarios. Manipulation of land cover and vegetation structure can further improve landscape resilience; in a predominantly forested landscape creating different stand structures increases microclimate variation between and within stands and glades (Morecroft *et al.,* 1998). In a largely open landscape encouraging small woods, tree lines and scattered trees, e.g. along river corridors, field boundaries and breaks of slope has a similar effect.

Such manipulation should allow more species to be able to spread through at least the local landscape, to take advantage of differences in microclimate conditions. Models of this landscape ‘permeability’ have been used to explore the best places to put new woodland to facilitate species movement (Watts, 2006; Watts *et al.,* 2007). Further work is needed to validate the underlying assumptions in these connectivity models; for example, as the cover of suitable habitat increases, the benefit of deliberately targeting the location of additional habitat declines (Pearson and Dawson, 2005).

There is a tension between maintaining separate, dispersed populations of species to reduce the risk of localised extinction from catastrophic events and promoting networks to create opportunities for migrations and adaptation to change (Nabuurs *et al.,* 2007). In the UK, the balance of advantage is seen as being more towards promoting networks, because pests and pathogens are not particularly limited in their dispersal, at the scale of UK landscapes.

Some of the adaptation measures for biodiversity involve increases in woodland cover – woodland creation. Other woodland creation schemes (to provide carbon sequestration, improve water supply, produce wood fibre or fuel) may not have biodiversity as a prime objective, but are likely to have some negative impact on biodiversity of open ground. Some 20th century afforestation schemes have developed into valued new cultural landscapes, with their own distinctive nature conservation values; others have not; and some are targeted for modification under open habitat restoration programmes. The history of past conflicts (e.g. Symonds, 1936; Nature Conservancy Council, 1986; Tompkins, 1989) colours reactions to afforestation proposals, so that new woodland creation must therefore be developed sensitively with full recognition of the potential implications for biodiversity, alongside the other associated costs and benefits.

Triage at the landscape level may help guide action for woodland species:

- In landscapes with little inherent robustness and low permeability, action concentrated on and immediately around individual sites may be more cost-effective than work on improving the landscape matrix, where more effort is needed to make a significant difference.
- Landscapes with intermediate vulnerability or permeability are a high priority for creating new woodland (or other habitats) to improve the landscape permeability,

since there is the potential to make a large difference with relatively little effort.
- In landscapes with low vulnerability or high permeability, additional woodland or habitat creation may make little difference to the landscape's adaptive capability for the majority of woodland species.

9.4.3 Social values of woodland

Many social values of woodland are related to how accessible they are. In future, increased emphasis may be placed on accessibility without reliance on cars. Adaptation might therefore be considered in terms of the match between tree and woodland distribution and population density: how much woodland is physically accessible via public transport, footpaths, for example (McKernan, 2007; Woodland Trust, 2004); and the degree to which it is actually accessed when cultural and behavioural factors are included (Burgess, 1996). The importance of local accessibility increases for short visits while for more remote, but attractive forest areas, the available accommodation and the range of activities are the important factors. Forest design, structure and relative openness are important, but the composition, in terms of tree species, tends to be less so (e.g. Coles and Bussey, 2000). There is some favouring of broadleaves over conifers by forest visitors, but this may be outweighed by the age and or size of the trees. In contrast, forest owners and managers are likely to consider the ease of maintenance or robustness to anti-social behaviour of the trees and woodlands.

A second element of social adaptation is helping people prepare for the changes in landscape appearance that will undoubtedly occur. For example, if beech becomes less common in the Chilterns; if oak spreads through some native pinewoods; or the balance of woodland and open land changes, the reasons for this need to be explained if unnecessary pressure to resist these changes is to be avoided. Both rapid increases and decreases in tree and woodland cover can generate active local opposition, which diverts resources from other adaptation measures.

9.4.4 Dealing with pests, pathogens and other disturbances

A landscape-level approach can help in planning for future potential climate change-related threats, whether these are abiotic or biotic. Some examples of such action are: deer management groups; organised control/eradication of potential hosts to new diseases (Rhododendron as a host of *Phytophthora ramorum* and *P. kernoviae* and timber movement restrictions to reduce spread of *Dendroctonus micans*). The impact of new diseases on large-scale plantations is often emphasised because of the economic consequences, but native species in semi-natural stands are not immune, as shown by Dutch elm disease, alder dieback, and current concerns over 'acute oak decline'. Across Europe, oak is considered, like pine and spruce, to be potentially vulnerable to major diseases (Lindner *et al.,* 2008), including outbreaks of pests and pathogens not currently found in the UK.

There is the potential for 'new' species to become invasive: these may be recent arrivals (oak processionary moth) but could also be species that have been long established in parks and gardens. For example there is some concern that *Robinia pseudacacia* might become a more aggressive invader of both woodland and non-wooded habitats under a warmer climate.

Increased risks of fire and possibly severe storm damage should be considered at the landscape level. Lessons can be learnt from the responses to past landscape-scale disturbances, such as the effects of the 1987 storm in southeast England (Kirby and Buckley, 1994; Grayson, 1989). There may also be interactions between climate change effects and pollutants, such as nitrogen deposition, that increase risk. For example, increased carbon dioxide and increased nitrogen may initially lead to increased tree growth but higher summer temperatures may combine with traffic pollution to increase levels of ozone, leading to increased damage to trees (see Chapter 3).

9.5 Adaptation measures at site level

Individual owners and managers can reduce the impact of climate change on the ability of their woods to deliver their desired range of objectives through altering the silvicultural system, the structure of the forest within a system and the main crop species used (Lindner *et al.,* 2008; Forestry Commission (a) in press; see also Section 3). The silvicultural system *per se* is, however, less important than the structures that it creates and their resilience and robustness in relation to future needs and conditions.

It would be possible to develop adaptation prescriptions based on the Forest Management Alternatives which were described in Section 3 and the majority of woods are likely to be treated as high forest in different forms (FMAs 1–4). Whereas clearfell systems have predominated in the past, continuous cover forestry approaches are increasingly promoted because they maintain a more even carbon storage, show lower soil carbon losses during harvesting, and maintain more even humidity levels. Mixed-age structured woods may be more resilient in the longer term. However, moving from even-aged to uneven-aged structures often involves short- to medium-term costs in production, biodiversity or social acceptance during the transition. Where the balance of advantage lies will often involve a range of site-specific factors.

For example, woods might be made more structurally diverse by reducing coupe size and encouraging continuous cover forestry. This may make the woods less susceptible to extreme windthrow, but increase harvesting costs and make the wood look more uniform in distant views. Shade-bearing woodland plants might benefit but the habitat available for species associated with open woodland might decline. Other examples of the trade-offs that have to be considered are that coppice and pollard systems maintain cultural continuity and past genetic variation by prolonging the life span of individual trees, involve very little soil disturbance to achieve regeneration, but reduce the potential for genetic change between generations. Dense natural regeneration provides more potential for natural selection to operate, but may require more intervention to achieve (such as fencing to remove grazing and scarification to improve establishment). Reducing rotation lengths will result in loss of potential old growth development, but permits more rapid testing of genetic material and thus may increase adaptation to the emerging new conditions (Hubert and Cottrell, 2007).

Young stands are usually faster growing than old ones, and so may sequester carbon more rapidly. However, old growth stands also build up carbon in the form of slowly decomposing organic matter in litter and soil (Luyssaert *et al.,* 2008; Zhou *et al.,* 2006) and are highly valued for biodiversity. More varied woodland, both in species composition and structures, means that there may always be some stands present that are vulnerable to particular threats which will result in chronic low-level disturbance. However, high diversity should make it easier to contain major disturbances because only a minority of stands are ever at the susceptible stage at any one time. This approach is already practised with respect to wind-hazard management (Gardiner and Quine, 2000).

Forestry and woodland management makes only limited use of external inputs of fertiliser, pesticides and other agrochemicals, and therefore do not have a large burden of the embedded carbon costs involved in their manufacture. However, the scope for further reduction of external inputs should be considered, for example by careful matching of species to site type (Pyatt *et al.* 2001); or stand manipulation to control competing ground vegetation. Where high production is needed, the use of nitrogen-fixing species as part of the crop mix might be appropriate, although the impact on biodiversity needs to be considered. Alder is the only native tree to fix nitrogen, but some non-native trees and shrubs are being tried (Hemery, 2001).

9.6 Adaptation in tree species choice

Climate change will affect the survival and growth patterns of tree species, with consequences both for semi-natural woodland composition and for production patterns and growth potential. The impact and the need for adaptive action will depend on whether desirable species are increasing or decreasing; whether they are major or minor parts of forest systems; and whether there is a net change in species occurrence and/or abundance overall. Where species are at the boundaries of acceptable growth (e.g. Norway spruce in eastern England), alternatives need to be sought; and even where the species remains within its tolerances, different provenances may be required (Broadmeadow and Ray, 2005; Ray, 2001). From a biodiversity perspective, species currently native only in southern Britain (e.g. beech), should become accepted in northern Britain; species from the near continent (e.g. sycamore) accepted in southern Britain, as part of the re-sorting of species that is likely to follow climate change (see Box 9.3).

As the progress of climate change becomes clearer, an even wider range of species may need to be considered (Table 9.1). Most of the species in this Table are already grown in Britain, at least in collections. From a biodiversity and landscape perspective, more emphasis should be placed on the broadleaved species as these are more likely to produce stands that are close in ecological and visual terms to current semi-natural woodland over most of the country. Further work is however needed on this approach and which particular species to include.

Uncertainties over future growth and potential threats to particular species (e.g. Brown and Webber, 2008) has led to favouring the use of mixtures of species and provenances at a variety of scales as an 'insurance mechanism' (Broadmeadow and Ray, 2005). Lady Park Wood in the Wye Valley can be considered as a natural microcosm of how, over decades, different components of a mixed stand may be hit by different disturbances, but the site remains wooded (Peterken and Mountford, 1995). One approach may be to introduce to woods relatively small amounts of novel species and provenances (Lindner *et al.*, 2008) that may prove useful in the future. Where native tree species are involved, this could affect the genetic diversity that has developed in the UK during the current post-glacial period, although as the environment changes such diversity will change anyway. In addition, many UK populations are exposed to long-distance wind pollen transport and to mixing with 'non-native' material from parks and gardens, for example. A general insistence on local provenance in native species planting may no longer be tenable, although it should remain a consideration, particularly where minor or insect-pollinated species are concerned. However, introductions of species and provenances have risks, notably the risk that the material will spread in woods or open ground where it is not wanted. Therefore, risk assessments for tree species need to be developed.

Table 9.1
Continental European tree species not native to the UK that warrant consideration as 'alternative species' in developing climate change adaptation strategies.

Broadleaf species	Conifer species
Acer monspessulanum	*Abies alba*
Acer opalus	*Abies borisii-regis*
Alnus cordata	*Abies cephalonica*
Castanea sativa	*Abies cilicica*
Celtis australis	*Abies pinsapo*
Fagus orientalis	*Picea omorika*
Fraxinus angustifolia	*Pinus brutia*
Juglans regia	*Pinus pinaster*
Ostrya carpinifolia	*Pinus pinea*
Platanus orientalis	*Pinus peuce*
Populus alba	
Quercus faginea	
Quercus ilex	
Quercus pyrenaica	
Quercus pubescens	

Table provided by Bill Mason, Richard Jinks and Mark Broadmeadow.

9.7 Advice and regulation adaptation

The foregoing sections have implications for how woods are managed and regulated. Some of what is required will be new. However, much will be a challenging extension (because of the major uncertainties about climate change and its impacts) of the current paradigm of sustainable forest management (Forestry Commission (b) in press).

Practical adaptation measures need to be tailored to the different types of woods, woodland owners and their objectives. Developing and implementing adaptation measures for coniferous production forests is likely to be easier than for the broadleaved/semi-natural resource. The former are already managed more actively and the ownership is more concentrated among the public forest estate and large management companies. There is also a need to revisit conservation designations and guidance: to develop site objectives and designation practices that can cope with more dynamic environments both for wooded and non-wooded habitats; and review approaches and attitudes to non-native species from the near continent. Perhaps as big a challenge as adapting to the changes in the physical climate will be responding to developments in policy, regulation and public attitudes. Such changes are hardly likely to be less frequent than over the last 60 years (see also Chapter 5).

9.8 Research priorities

Given the uncertainty identified above, there are some pressing research needs:

- Development of databases and knowledge on how different species are expected to respond to climate change (e.g. Ecological Site Classification, Climate Envelope Modelling, see Chapter 4), matched by studies on how their populations and distributions are actually changing (including new provenance/species trials).
- Improved understanding as to which factors will become limiting for which species at a regional level; and how climate change factors will change disturbance regimes of wind, fire, pests and pathogens.
- Improved understanding of how climate change factors will change disturbance regimes of wind, fire, pests and pathogens.
- Exploration of the scope for and limits of 'technical fixes' such as species translocations, genetically improved trees, and so on.

- Improved modelling of how climate impacts on other land uses and societal behaviour will impact on trees, woods and forestry, combined with development of appropriate decision-making methods that can deal with uncertainty and integration of different societal values.
- Improved monitoring and modelling of the degree to which more varied composition and structure does improve resilience; and studies of how to measure the economic value of changes in forest system resilience.
- Improved understanding of appropriate decision making methods, including methods of dealing with uncertainty and the integration of multiple societal values.
- Developing practical ways of applying research results to effect change across landscapes that integrate areas of high social and productive land use with those where conservation has a higher priority (*cf.* a revitalised Man and the Biosphere programme?).

9.9 Conclusions

Adaptation needs to be an ongoing process, with continuing testing of orthodoxies and re-calibration of experiences, which have often been based on a static view of the natural and social environments, a focus on preservation of past structures, communities, systems or markets. Equally, views on and understanding of climate change and its impacts will evolve. Incentives, controls, education and knowledge transfer need to be kept in line with progress on adaptive measures. Ultimately it will be a case of accepting the impacts and changes we can make little difference to; concentrating our efforts on those which can be changed; and having the wisdom to separate the two.

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WOODLANDS HELPING SOCIETY TO ADAPT

Chapter 10

J. F. Handley and S. E. Gill

Key Findings

In a changing climate, tree and woodland cover in and around urban areas becomes increasingly important for managing temperatures, surface water and air quality. Large tree canopies are the most beneficial, and guidelines should be followed by all concerned parties to ensure that we continue to maintain and plant such trees in urban areas and to overcome perceived risks including subsidence and windthrow. Care should be taken to select tree species which will not contribute to urban ozone pollution and, where water stress is likely to be a problem, planting should focus on more drought-tolerant species.

It is crucial that we have a thorough understanding of the current pattern of tree cover in urban areas, to target where we need to maintain and increase cover. Tree and woodland creation in urban areas should then have two key aims: to manage temperatures and to manage surface water.

The role of trees and woodlands in managing temperatures is clear. Tree and woodland planting should be targeted to: (1) places where people live (especially the most vulnerable members of society) which currently have low tree cover; (2) places where people gather (such as town and local centres), which currently have low tree cover. There is a need for clearer guidelines to encourage the establishment of tree cover in town centres and high density residential areas. Such guidelines need to cover the perceived risks from subsidence and windthrow.

Trees and woodlands have a role to play in managing surface water in urban areas. Their interception of rainfall could be significant. Planting here could be targeted to soils with higher infiltration rates and areas with a history of surface water flooding.

In a changing climate, woodland cover in rural areas will also have a role in helping society, as well as other species, to adapt. Its main role is in managing water resources and reducing flooding. The impact of woodland on water resources will become increasingly important and care will be needed in woodland siting and design to reduce potential losses of water. Its role in managing flooding is more complicated. Large-scale planting in catchments is neither feasible nor likely to control extreme floods, and could indeed have a significant adverse impact on water resources. Targeted woodland creation to manage flooding and improve water status is more effective and could be very beneficial. This would include: planting woodland on (or downslope of) soils vulnerable to erosion and structural damage, woodland buffers along watercourses, planting on derelict and disused land and as a priority, re-creation of carefully designed and located floodplain and riparian woodland.

The overall climate change picture for the UK is summarised in Chapter 2 of this report. Regional studies of climate change impacts (including potential benefits and opportunities) have been carried out throughout the UK as part of the UK Climate Impacts Programme (Box 10.1).

The detailed picture varies from region to region, reflecting changing socio-economic patterns and the strong climate gradient from south east to north west across the UK.

This chapter explores whether trees and woodland, particularly in and around urban areas, can help to moderate the societal impacts of climate change and realise potential 'benefits'. Climate change is expected to bring with it a more outdoor lifestyle and to increase the variety and intensity of visitor use in recreational landscapes (Box 10.1). Managed forests with their ready-made access network are well placed to help meet such demand close to urban centres (e.g. Delamere Forest in northwest England) and to deflect pressure from more fragile landscapes (e.g. Grizedale Forest in the English Lake District).

BOX 10.1 Key threats and opportunities of climate change impacts in the UK

The most widely recognised problems include:

- an increase in the risk of riverine and coastal flooding and erosion
- increased pressure on drainage systems
- a potential increase in winter storm damage
- habitat loss
- summer water shortages, low stream flows and water quality problems
- increased risk of subsidence in subsidence prone areas
- increasing thermal discomfort in buildings and health problems in summer.

Common benefits include:

- a longer growing season and enhanced crop yields
- less cold weather, transport disruption
- reduced demand for winter heating
- fewer cold-related illnesses and deaths.

Opportunities include:

- agricultural diversification and the potential to grow new crops
- an increase in tourism and leisure pursuits
- a shift to more outdoor-oriented lifestyles.

Source: Regional Scoping Studies, West and Gawith, 2005

The degree of urbanisation is especially significant given the concentration of people and property in urban areas, together with the way in which urbanisation itself influences the local climate (Wilby, 2007; Gill *et al.,* 2007). Climate change adaptation strategies need to operate at a series of interlocking spatial scales, an approach exemplified by Shaw *et al.,* 2007, which identifies three levels of inquiry: conurbation or catchment scale, neighbourhood scale and building scale.

Trees and woodland have a potential contribution at each level of scale, and particularly in and around urban areas, in moderating the societal impacts of climate change and realising potential 'benefits'. The ensuing review takes a multi-scalar approach and focuses on the role of trees and woodland with regard to two key impacts of climate change: higher temperatures and changes to the hydrological cycle. It then explores how these roles can be realised in practice, in spite of climate-related hazards.

10.1 Managing high temperatures

Heat waves are expected to increase in frequency and severity in a warmer world (IPCC, 2007; Meehl and Tebaldi, 2004) and urban heat islands will exacerbate the effects of regional warming by increasing summer temperatures relative to outlying districts (Wilby, 2003). Heat stress is likely to increase morbidity and mortality both directly and indirectly through cardiovascular and respiratory disease, which may be further exacerbated by an interaction between temperature stress and air pollution (Davis and Topping, 2008). The severe heat wave in southern and central Europe in 2003 which extended from June to mid-August may have caused 35 000 excess deaths, especially among the elderly (Kosatsky, 2005). Average summer temperatures (June to August) exceeded the long-term mean by up to five standard deviations, but this extreme event is well within the range anticipated by climate models for the 21st century (Stott *et al.,* 2004). Renaud and Rebetz (2009) compared below-canopy and open-site air temperatures at 14 forest sites in Switzerland over 11 days during the August 2003 heat wave. Maximum mean temperatures were significantly cooler (up to 5.2ºC) under the canopy, with broadleaved and mixed forests containing beech being particularly effective. They commented on the potential role of forests to provide cool shelter, especially in urban areas, 'where forested parks could provide an important source of relief during heat waves' (Renaud and Rebetz, 2009, p. 873).

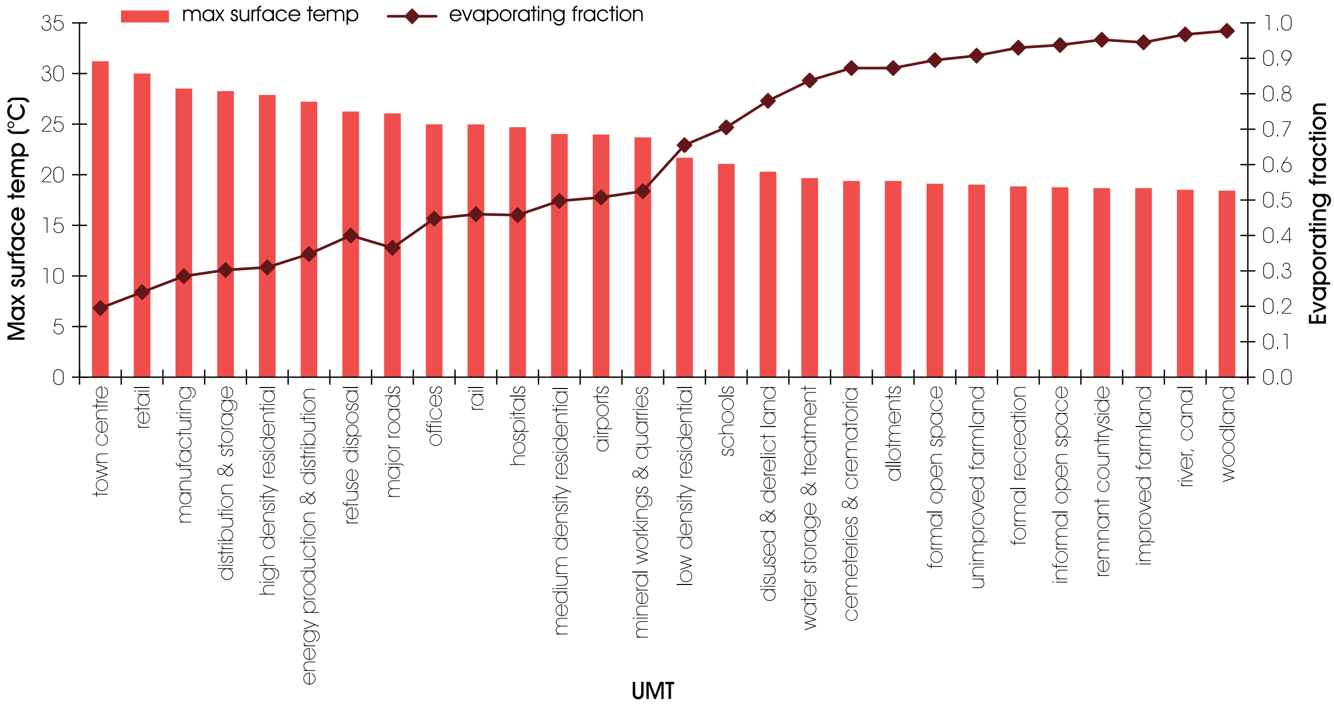
In fact, the importance of trees and woodland for the urban microclimate has long been recognised. Oke (1989) notes that tree cover in urban areas frequently exceeds that of the surrounding peri-urban environment and that the trees collectively constitute an 'urban forest'. He reviews the influence of the urban forest on micrometeorology at a range of scales, noting the:

> 'radiative, aerodynamic, thermal and moisture properties of trees that so clearly set them apart from other urban materials and surfaces in terms of their exchanges of heat, mass and momentum with the atmosphere. Their resulting ability to produce shade, coolness, shelter, moisture and air filtration makes them flexible tools for environmental design' (Oke, 1989, p. 335).

Indeed, provision of vegetation, particularly large broadleaved trees is proposed as one of the more effective strategies for maintaining human comfort during high temperature episodes in urban areas (Watkins *et al.,* 2007). Bioclimatic design at the city scale requires an understanding of both the moderating role of vegetation (the green infrastructure) and the need to maintain ventilation and cool air drainage (Oke, 1989; Eliasson, 2000). European cities such as Stuttgart have long been planned with such considerations in mind (Hough, 2004) and it is important that planting design facilitates, rather than obstructs, ventilation. The current state of the art in bioclimatic planning and design is exemplified by the city of Berlin (Berlin Digital Environmental Atlas, 2009; www.stadtentwicklung.berlin.de/umwelt/umweltatlas/edua_index.shtml).

Besides providing shade, urban greenspace contributes to cooling through evapotranspiration. Modelling studies in Greater Manchester have shown significant differences for surface temperature between different urban morphology types, depending on the amount of greenspace present (Figure 10.1). At the neighbourhood level, a 10% decrease in urban green results in an increased maximum surface

Figure 10.1
Urban morphology types (UMTs) plotted in order of maximum surface temperature for 1961–1990 along with evaporating fraction (Gill, 2006).



temperature of 7°C in high density residential areas and 8.2°C in town centres (compared with the 1961–1990 current form case) under the UKCIP02 2080s high emissions scenario (Gill *et al.,* 2007). By contrast, adding 10% green cover keeps maximum surface temperatures at or below the 1961–1990 baseline up to, but not including, the 2080s high emissions scenario (Figure 10.2). There are large differences in tree cover with changes in residential density; in Greater Manchester for example, average tree cover varies from 27% (low density) through 13% (medium density) to 7% (high density). The high density areas include wards where socio-economic disadvantage and ill-health are concentrated and active greening programmes will be needed to ensure that residents are not further disadvantaged by climate change (Tame, 2006).

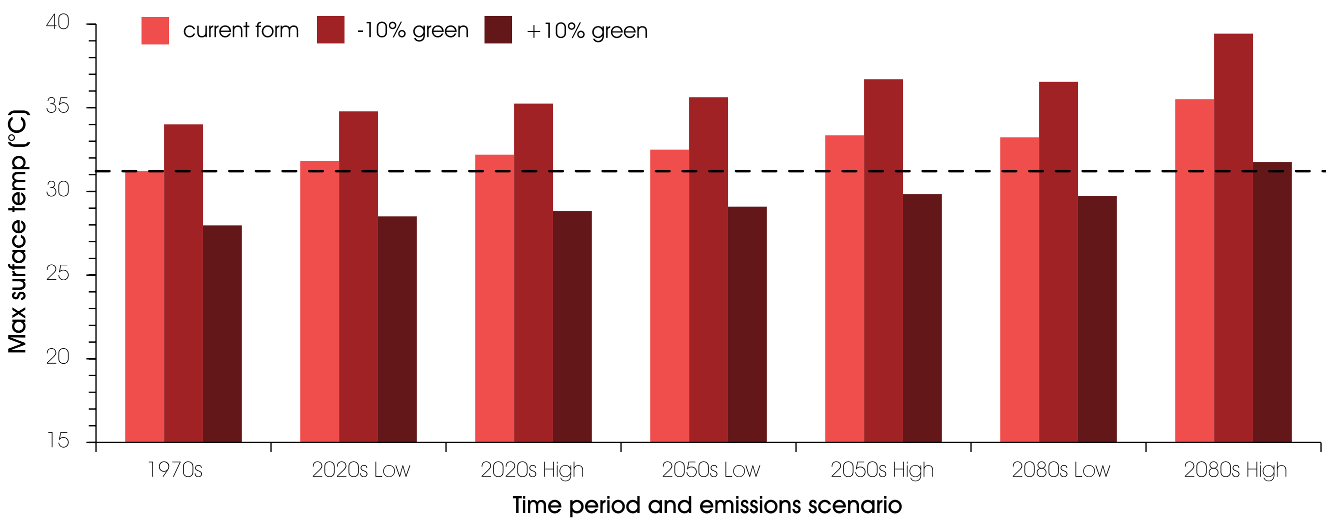
Surface temperature is just one among a number of parameters that determine human comfort; these include air temperature, radiant temperature field, direct solar radiation, air speed and humidity (Watkins *et al.,* 2007). Studies in Hungary (Gulyás *et al.,* 2006) and Germany (Mayer and Höppe, 1987) show a strong correlation between radiation modifications and changes in thermal stress, focusing on the role of trees; especially large canopy deciduous trees in the public realm. We have seen that a shift to a more outdoor-oriented lifestyle is likely to accompany climate change in the UK (Box 10.1). Wilson et al. (2008) have endorsed this and emphasised the role of well designed (and well treed) public open spaces in building adaptive capacity. Parks, with mature trees, will provide cool lacunae in an increasingly inhospitable urban environment with microclimatic benefits which can extend beyond, into surrounding urban neighbourhoods (Oke, 1989; Spronken-Smith and Oke, 1998). It is however vital to ensure that appropriate water supplies are available to sustain urban greenspace, and its evaporative cooling function, in periods of heat stress which will inevitably coincide with periods of potential soil water deficit (Gill *et al.,* 2007 and Watkins *et al.,* 2007). Drought tolerance could become an increasingly important consideration in tree species selection for planting schemes.

The wish to escape from uncomfortably hot, poorly ventilated offices, shops and public buildings will create the need to adapt public space (Wilson *et al.,* 2008). The UK building stock is not well adapted to a warmer climate and problems of thermal comfort are already being experienced in London (Hacker and Holmes, 2007). Rather than install air conditioning (which drives up energy use and therefore GHG emissions), these authors advocate the use of advanced passive features, including shade. Retrofitting buildings is difficult and therefore broadleaved trees may have an important contribution to make (Huang *et al.,* 1987; Simpson, 2002). Indeed in the USA, tree planting programmes have been devised with the express intention to reduce or avoid peak energy demand for cooling (Akbari, 2002; McPherson and Simpson, 2003).

10.2 Responding to change in the hydrological cycle

'Future Water', the UK government's water strategy for England states:

Figure 10.2
Maximum surface temperature in the town centre UMT with current form and plus or minus 10% green cover (black dashed line shows 1961–1990 current form temperature) (Gill, 2006).



> 'Climate change is already a major pressure. With predictions for the UK of rising temperatures, wetter winters, drier summers, more intense rainfall events and greater climate variability, we can expect to experience higher water demand, more widespread water stress with increased risk of drought, more water quality problems, as well as more extreme downpours with a greater risk of flooding' (Defra, 2008).

It is clear that climate change impacts on society will be powerfully mediated through change in the hydrological cycle. Water shortage in summer is unlikely to be compensated by excess rainfall in winter which will, in turn, increase flood risk, especially in urban areas. The Foresight Report on Future Flooding (Evans *et al.,* 2003) sought to quantify the economic consequences of increasing flood risk. Their work was updated and summarised by Sir Michael Pitt in his review of the June/July floods of 2007 (Pitt, 2008). The new analysis indicates the potential for even warmer and wetter winters, together with summers that are also warmer but not quite so dry as previously predicted. The increased intensity of rainfall, in both winter and summer, increases the risk from intra-urban (i.e. surface water) flooding in urban areas.

Woodland is potentially beneficial in helping society to adapt to climate change because of its ability to intercept rainfall, some of which is evaporated back to the atmosphere before it reaches the forest floor by stemflow and throughfall. Within woodland, the infiltration of that water is more effective than under alternative types of land cover and forest soils tend to be deeper, and therefore contain a greater storage capacity. It follows that woodland may help to moderate peak flows of water in high rainfall events, while sustaining infiltration to aquifers and baseflow in rivers during periods of drought. Thus, commentators such as Seppälä (2007), when writing about forestry and climate change are able to assert that 'forests maintain much of the water supply, and trees make a contribution to water management and hence reduce the threat of flooding and erosion'. The extent to which such claims can be sustained in the face of scientific evidence, and their relevance in a UK context is, however, very much open to debate (Newson and Calder, 1989; McCulloch and Robinson, 1993; Calder and Aylward, 2006; Calder, 2007). The position is well summarised by Calder (2007) in a paper which evaluates forest benefits against water costs and argues that forest management programmes need to be set in the context of long-term sustainable land and water management.

Some of the adverse impacts of forests on the water cycle identified by Calder (2007) are actually a function of poor forest management and in the UK much has been learnt about how problems of enhanced runoff and sediment yield can be avoided by good husbandry (Forestry Commission, 2003a).

Here, three issues concerning the role of trees and woodland in helping society to adapt to climate change are considered:

1. The impact of trees and woodland on water supply
2. The impact of trees and woodland in moderating flooding
3. The impact of trees and woodland in managing surface water runoff within urban areas.

10.2.1 The impact of trees and woodland on water supply

We have seen that sustaining the quantity and quality of water supply is likely to become a critical issue for society in a changing climate; indeed it already presents a severe challenge in the south and east of England. Water use by trees and woodland and its implications for water supply

Table 10.1
Typical range of annual evaporation losses (mm) for different land covers receiving 1000 mm annual rainfall (Nisbet, 2005).

Land cover	Transpiration	Interception	Total evaporation
Conifers	300–350	250–450	550–800
Broadleaves	300–390	100–250	400–640
Grass	400–600	–	400–600
Heather	200–420	160–190	360–610
Bracken	400–600	200	600–800
Arable*	370–430	–	370–430

* Assuming no irrigation

has been very effectively reviewed by Nisbet (2005). Table 10.1 provides comparative data on annual evaporation losses between different types of forest cover and a range of alternative land covers.

While interception loss tends to be greater for woodland, transpiration rates are somewhat reduced due, among other factors, to more effective stomatal control (Roberts, 1983). The multifarious influences of climate, geology, forest management, design, scale and land cover make it difficult to generalise about the effects of forestry on water resources. Nevertheless, some important distinctions can be drawn between the likely impact of conifers and broadleaves in the uplands and lowlands, respectively (Nisbet, 2005), as shown in Table 10.2. Climate change, with enhanced temperatures in both summer and winter throughout Britain, will increase evaporation, and this, together with seasonal changes in rainfall, could exert a strong influence on forest water use and water yields (Nisbet, 2002). The drive to plant more forest energy crops for renewable fuel could further increase the threat to water supplies (Calder *et al.,* 2009).

It follows from this discussion that the role of trees and woodland in the management of water resources is likely to become more important in the future as the combination of rising water demand and the likelihood of drier summers generates even greater pressure on water resources. Application of the precautionary principle suggests that the extensive planting of woodland, especially of conifers would require very careful evaluation from the perspective of water yield, particularly over significant aquifers in the English lowlands.

10.2.2 The impact of trees and woodland in moderating flooding

We have seen that in principle, woodland should be

Table 10.2
Impact of woodland on water yield.

Conifer woodland/upland	Broadleaved woodland/upland
• Evidence available from major catchment studies in Wales (Plynlimon), England (Coalburn) and Scotland (Balquhidder). • For every 10% covered by mature forest Calder and Newson (1979), suggest a 1.5–2.0% reduction in water yield. • More recent evidence suggests impact of well designed, mixed age forest may be somewhat less on whole forest rotation and impact of forest may decline with time (e.g. Hudson *et al.,* 1997) • Difficult to identify a response to felling of between 20 and 30% of forested catchment.	• No, or very limited, research evidence available. • For secondary (scrub) woodland colonising upland landscapes surmised that the light leaved species involved (e.g. birch and rowan) unlikely to increase interception significantly above moorland (e.g. heather).
Conifer woodland/lowland	**Broadleaved woodland/lowland**
• Interception and transpiration loss becomes proportionately more significant as rainfall is reduced. • Long-term recharge rate reduced by 75% under pine compared with grassland over sandstone in English midlands (Calder *et al.,* 2003). • For years of average annual rainfall no recharge at all beneath pine forest on this midlands' site (Calder *et al.,* 2003) • Spruce in Netherlands reduces water recharge by 79% compared with arable land (Van der Salm *et al.*, 2006).	• Long-term recharge rate reduced by about half (48%) beneath oak compared with grassland on sandstone in English midlands (Calder *et al.,* 2003). • Oak in Netherlands reduces water recharge by 64% compared with arable land (Van der Salm *et al.,* 2006) • Drainage water from beech over chalk in Hampshire estimated to be 13% greater than grassland during 18 month measurement period (Roberts *et al.,* 2001). • However, grass drainage could exceed that of woodland on chalk in very wet years due to much higher woodland interception loss (Roberts *et al.,* 2001)

effective at reducing overland flow, and therefore peak discharge from catchments, during high rainfall events. Soils under natural forests tend to be relatively porous with high infiltration rates and consequently low rates of surface runoff, and generally exhibit low rates of erosion (Calder and Aylward, 2006).

In a recent European study, Serrano-Muela *et al.* (2008) provide an elegant demonstration of these properties from an undisturbed forest catchment (San Salvador) in the Spanish Pyrenees, which is contrasted with neighbouring deforested catchments. The forest cover significantly moderates flood response until late spring when following recharge of the soil profile and a heavy rainfall event, the flood peak is similar to that of the deforested catchment. Thus, mature forests reduce the number of floods but do not significantly alter the hydrological impacts of extreme rainfall. It is clear that as the severity of the flood increases, the impact of land use change appears to be reduced (Calder and Aylward, 2006). Similarly, the impact of forests on peak flows becomes harder to detect as the geographical scale of inquiry is increased. Robinson *et al.* (2003) studied 28 river basins across Europe sampling a wide range of managed forest types, climates and ground conditions. They concluded that:

> 'For all the forest types studied the changes to extreme flows will be diluted at the larger basin scale, where forest management is phased across a catchment, or only a part of the basin is forested. Overall, the results from these studies conducted under realistic forest management procedures have shown that the potential for forests to reduce peak and low flows is much less than has often been widely claimed' (Robinson *et al.,* 2003, p. 96).

These findings are broadly in line with a major review of the impacts of rural land use and management on flood generation commissioned by Defra (O'Connell *et al.,* 2004) which assessed and critiqued the available literature. Their conclusions have been neatly summarised by Heath *et al.* (2008):

- The past 50 years have seen a significant intensification of agriculture, with anecdotal evidence that this has had an effect on flood peaks.
- There is evidence from small-scale manipulation experiments that land use/management has a significant effect on runoff at local scales.
- There is very limited evidence that the effects of land use/management can be distinguished at catchment scales in the face of climate variability.
- There is evidence that surface flow can be reduced by local land management, but effects on flood peaks may depend on spatial and temporal integration to catchment scales.
- It is not possible (at least yet) to rely on rainfall-runoff modelling to predict impacts of land use/management changes.

It seems that while large-scale woodland creation could not be justified on the grounds of flood control alone, there are specific situations where carefully designed woodland planting could be beneficial. These are discussed below.

Planting woodland buffers on compacted upland pastures

High stocking rates in upland pastures have resulted in soil compaction and reduced infiltration. Planting of woodland buffers normal to the direction of flow significantly boosts infiltration and can reduce overland transport of sediment (Carroll *et al.,* 2004; Ellis *et al.,* 2006; Marshall *et al.,* 2009). Recent modelling studies suggest that these effects could reduce local peak flows by 13–48% (Jackson *et al.,* 2008).

Riparian planting along stream sides

The planting of riparian woodland can also attenuate flood peaks by increasing hydraulic roughness and reducing wave velocity (Anderson *et al.,* 2006). It acts in a similar way to floodplain woodland but on a smaller scale. Thomas and Nisbet (2006) showed that the formation of large woody debris dams within stream channels could significantly lengthen local peak flow response times. Planting riparian woodland can also help flood control by reducing bank erosion, sediment delivery and the siltation of flood channels (Nisbet *et al.,* 2004). Other water benefits of riparian woodland are cited as reducing diffuse pollution through the capture of nutrients and pesticides draining from the adjacent land, and alleviating thermal stress to fish by shading (Calder *et al.,* 2008; Parrott and Holbrook, 2006).

Woodland establishment on disused and derelict land in the urban and peri-urban environment

Runoff modelling under climate change scenarios (Gill, 2006) suggests that derelict land is potentially significant in managing surface water flows in the urban and peri-urban environment. Such areas can act as a source or sink for surface water depending on their origin, condition, management and, when reclaimed, the nature of the after-use. Certain categories of disused and derelict land, e.g. colliery spoil, are often highly compacted (Moffat and McNeil, 1994); runoff from such areas is extremely rapid and can contribute to surface water flooding of residential areas. Afforestation not only relieves compaction, so improving infiltration and soil storage, but reduces runoff through interception and transpiration. The potential for woodland on derelict and disused land has been reviewed by Perry and Handley (2000) who identified a wide range of opportunities, including closed landfill sites. Bending and Moffat (1997) have shown that tree growth can be compatible with landfill integrity and here, woodland establishment could be particularly beneficial in reducing the potential for contaminative excess runoff.

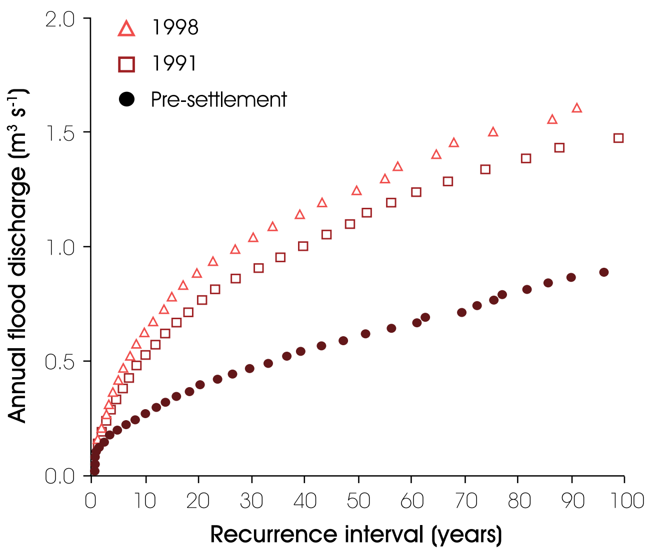
Flood plain forests to increase storage and attenuate flow

The recreation of floodplain woodland to delay the progression of floods may offer the greatest potential for forestry to assist flood control. The potential of floodplain woodland to attenuate flood peaks, as well as delivering associated benefits such as water quality, biodiversity, fisheries, recreation and landscape have been highlighted by Kerr and Nisbet, 1996. The flood attenuation principle relies on the hydraulic roughness created by woody debris dams within stream channels and the physical presence of trees on the flood plain. The net effect is to reduce flood velocities, enhance out of bank flow, and increase water storage on the floodplain so, potentially, moderating the downstream flood impact. Hydraulic modelling studies in southwest England indicate that planting woodland across the flood plain could have a marked effect on flood flows (Thomas and Nisbet, 2006). Implementation will need to address concerns such as flooding of local properties due to back-up of flood water and blockage of downstream structures by woody debris. Moreover, the attenuation of flood-flows in one sub-catchment will change the synchrony of the drainage network (which could be either problematic or highly beneficial) and therefore the location of floodplain forest needs to be carefully designed so as to reduce flood risk, rather than accentuate it.

10.2.3 The impact of trees and woodland in managing surface runoff within urban areas

Urbanisation of a catchment fundamentally changes its hydrological character, due to extensive surface sealing with reduced infiltration and enhanced surface runoff; much of that via the sewer network (Bridgman *et al.,* 1995). The effect of progressive urbanisation and deforestation on simulated flood frequency curves for a naturally wooded watershed is shown in Figure 10.3 (Wissmar *et al.,* 2004).

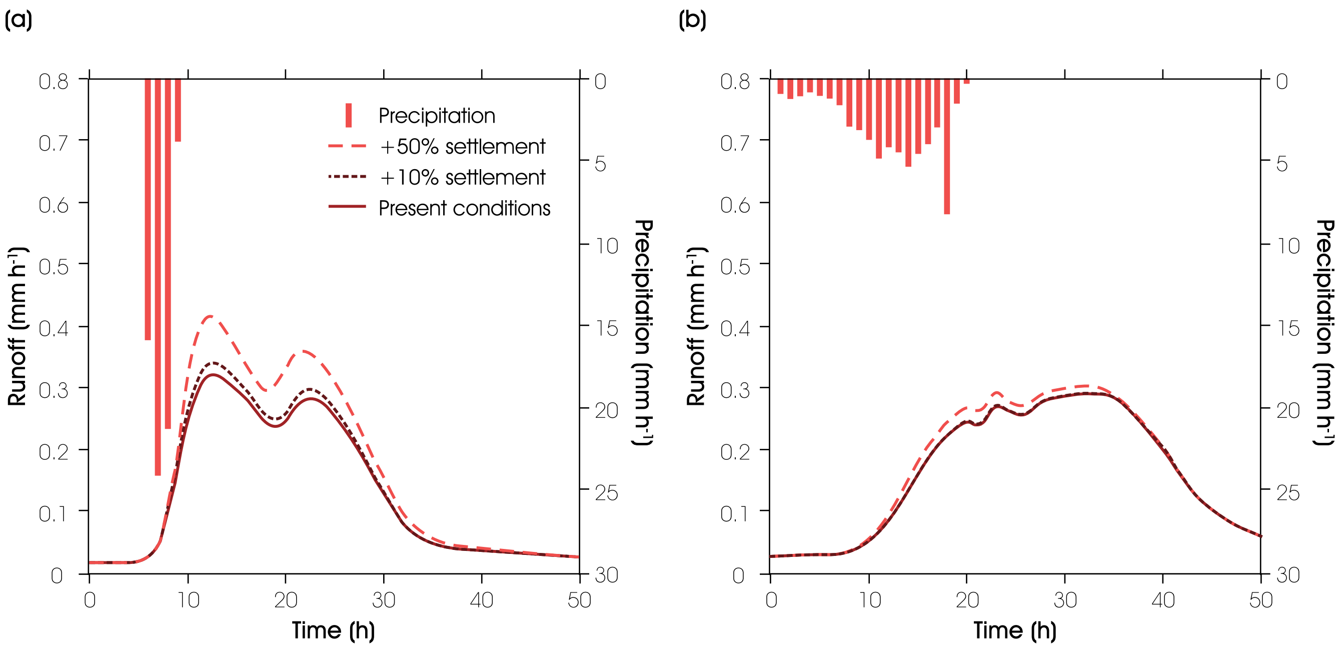
Figure 10.3
Simulated flood-frequency curves (m^3 s^{-1}) for Maplewood Creek. Flood-frequency curves indicate that annual flood discharge rates for 1991 and 1998 exceed pre-settlement discharge rates. Symbols: open triangles, the flood-frequency curve for 1998; open squares, the 1991 flood-frequency curve; solid circles, the flood-frequency curve for pre-settlement conditions. Pre-settlement conditions represent fully forested cover and no impervious surfaces.



With kind permission from Springer Science + Business Media: Environmental Management, Effects of changing forest and impervious land covers on discharge characteristics of watersheds, 34, 2004, 91–98, Wissmar, R.C., Timm, R.K. and Logsdon, M.G., Figure 2.

The profound implications of urbanisation for catchment behaviour are well illustrated by Bronstert *et al.,* (2002) who simulate the effect of two contrasting flood events on the Lein catchment (Germany). As shown in Figure 10.4, for high precipitation intensities, an increase in settlement leads to markedly higher peak flows and flood volumes, whereas the influence of urbanisation on advective rainfall events with lower precipitation intensities and higher antecedent soil moisture is much smaller. In this example, the increase in stream runoff for the convection event is mainly due to an increase in sewer overflow in settlement areas and infiltration-excess overload flow on farmland. This type of short duration, high intensity rainfall is likely to become more frequent with climate change, and the Pitt review (Pitt, 2008) highlights the potential for enhanced intra-urban or surface water flooding. However, the implications of changing patterns of rainfall on urban

Figure 10.4
Simulation of two flood events in the Lein catchment with a return period of approximately three years for present conditions and two urbanisation scenarios (10% and 50% increase in settlement area): (a) convective storm event; (b) advective storm event (Bronstert *et al.,* 2002).



With kind permission from John Wiley & Sons Ltd: Hydrological Processes, Effects of climate and land-use change on storm runoff generation: present knowledge and modelling capabilities, 16, 2002, 509–529, Bronstert, A., Niehoff, D. and Bürger, G.

drainage are even more pervasive, with significant consequences for water quality and waste-water treatment (Balmforth, 2002).

In the USA, conservation of native woodland is considered to be one of the most effective measures for countering the quantitative and qualitative impacts of urbanisation on river systems (Booth *et al.,* 2002). Indeed Matteo *et al.* (2006) drawing on the results of modelling studies, advocate the creation of woodland buffers along streams and highways with a view to handling adverse conditions such as large storms, non-point source pollution and flooding. Those characteristics of tree cover which are potentially problematic for water supply (notably rainfall interception) could be beneficial in managing flood flows in the urban environment. In the urban ecosystem, canopy rainfall interception changes the urban runoff process by reducing the flow rate and shifting the runoff concentration time via water storage on the canopy surface (Sanders, 1986). The high ventilation of the built environment could be expected to enhance woodland interception losses beyond the typical values of 25–45% for conifers and 10–25% for broadleaves (Nisbet, 2005). A decrease in storm runoff volume reduces flooding hazard, surface pollutant wash-off and pollutant loading of the runoff – all key features of summer storm impacts on urbanised areas in Britain. Having studied in detail rainfall interception by mature open-grown trees in Davis, California, Xiao and his co-workers (2000, p. 782) conclude that interception losses may be even 'higher in places that have frequent summer rainfall and warm, sunny conditions'. These properties are important because urban runoff reduction ultimately reduces expenditure on urban runoff control and waste-water treatment. These financial benefits have been quantified for settlements in California (Xiao *et al.,* 2002) and the research findings used to inform the design and management of the urban forest resource.

By contrast with the USA, the capacity of trees in the urban environment (i.e. the urban forest) to store and also to infiltrate water (Bartens *et al.,* 2008) tends not to have been recognised as part of sustainable urban drainage systems within the UK. Modelling in the Greater Manchester area (Gill, 2006; Gill *et al.,* 2007) suggests that increasing or decreasing the tree cover has an effect on runoff, especially on more porous soils. While under the type of extreme rainfall event that is envisaged in a changed climate, the capacity of urban trees to counter increased runoff is exceeded (Gill *et al.,* 2007), it does not follow that urban trees do not have a significant role to play within the storm water chain, especially under less extreme conditions. Research findings from the USA would suggest that broadleaved trees in British cities are already playing an important role in moderating runoff and protecting water quality. This role is likely to grow in importance, especially in summer, when Britain's broadleaved deciduous trees are best placed to intercept rainfall in intermittent summer storms.

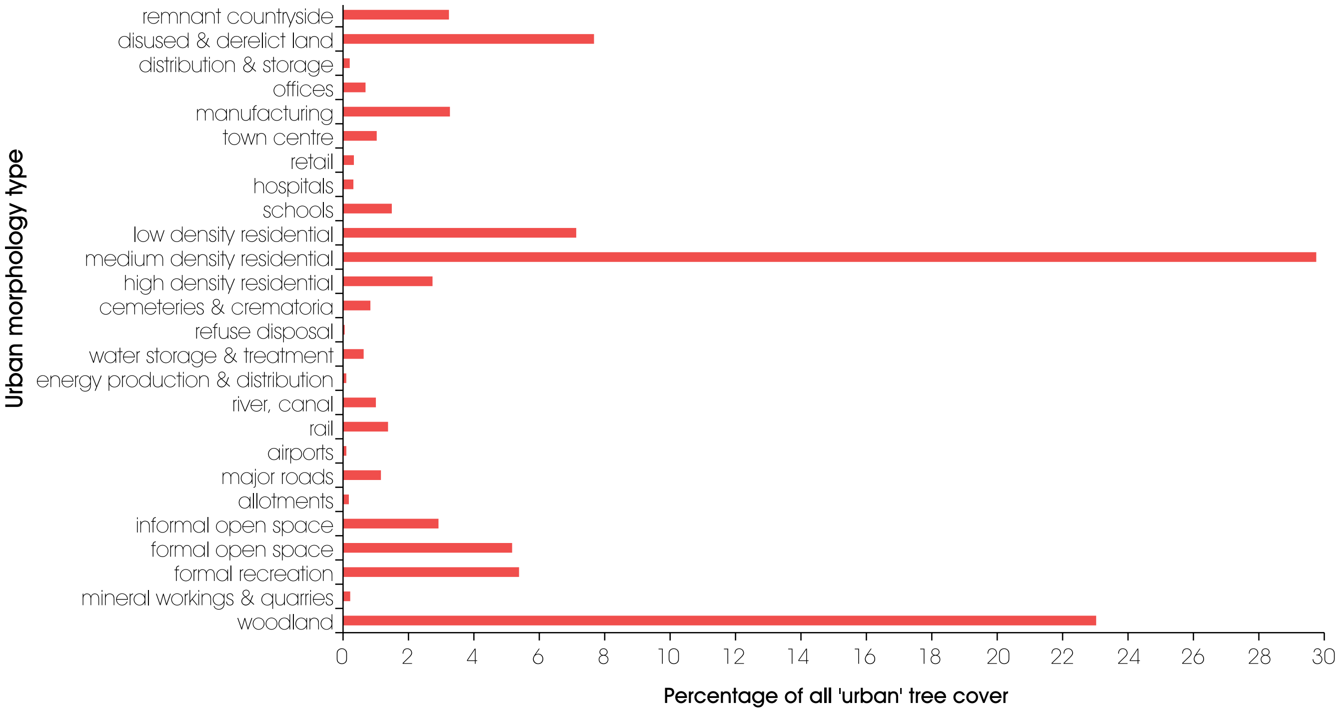
10.3 Managing trees and woodlands to optimise benefits to society and reduce climate-related hazards

The vision in Defra's Strategy for England's Trees, Woods and Forests begins: 'It is 2050, and England's trees, woods and forests are helping us to cope with the continuing challenge of climate change …' (Defra, 2007, p. 10). The climate change adaptation roles of trees and woodlands, discussed in the previous sections, will determine, to some extent, where we want our trees and woodlands to be in order to optimise the benefits to society. Trees and woodlands in rural areas have some role to play in helping society to adapt, in particular through strategic planting to manage riverine flood risk, water resources and quality, as well as helping other species to adapt and realising opportunity in visitor landscapes. However, the evidence set out above strongly makes a case for trees and woodland to be located where people are most concentrated; in the peri-urban and urban environments. It is here, where, along with the other adaptation roles, they can contribute significantly to managing high temperatures and reducing pressure on drainage systems.

In contrast to the USA, where tools to characterise the structure, function and economic benefits of urban forests have been developed, and assessments have been undertaken for many major cities (e.g. American Forests, 2009; Nowak, 2008), little is known in the UK, and indeed in Europe (Konijnendijk, 2003), about this urban forest. The 'Trees in towns' surveys highlight how little local authorities know about the urban tree populations in their district (Britt and Johnston, 2008; Land Use Consultants, 1993). Of the sites surveyed for 'Trees in towns II', the mean canopy cover was 8.2%. While town size had no effect on this, it does vary within urban areas according to land use; from 3.6% in industrial and high density residential areas to 22.8% in low density residential areas. A characterisation of Greater Manchester found that medium-density residential areas are especially important as they account for 37% of the 'urbanised' area, such that just under 30% of all the tree cover found in the urban areas occur here (Figure 10.5) (Gill *et al.,* 2008; Gill, 2006).

It is imperative that the trees and woodlands in urban areas are strategically planned and managed. Many local

Figure 10.5
Percentage of all surface covered by trees across 'urbanised' Greater Manchester (from data generated for Gill, 2006).



authorities lack basic information about the nature and extent of trees and woodlands in their district and, while a substantial number have produced tree strategies, these are often seriously deficient in terms of their content and detail (Britt and Johnston, 2008). 'Trees in towns II' calls for local authorities to develop and implement a comprehensive tree strategy, and that it is beneficial to think beyond trees to the wider context of urban green space and the environment (Britt and Johnston, 2008). This chimes well with recent moves towards green infrastructure planning, with trees and woodlands being significant components (e.g. North West Green Infrastructure Think Tank, 2008; Kambites and Owen, 2006).

There is clearly a need to bring tree cover into the most built up parts of our urban areas, including town centres and high-density residential areas. In addition, the most vulnerable members of society often live in areas with the lowest tree cover (e.g. Tame, 2006; Pauleit *et al.,* 2005). However, the Trees and Design Action Group has highlighted the huge gap between aspirations for more and larger trees in the urban realm and practical considerations which are creating a landscape devoid of large tree species. They are championing a 'new culture of collaborative working that places trees and their requirements at the forefront of the decision-making process' (Trees and Design Action Group, 2008, p. 1). This echoes a previous call by the Royal Commission on Environmental Pollution for the natural environment to be at the heart of urban design and management (RCEP, 2007). Indeed, certain perceived tree hazards could be compounded further by climate change. Below, we explore three of these: building and/or infrastructure subsidence, air quality (ozone precursors) and windthrow.

10.3.1 Building and/or infrastructure subsidence

On shrink-swell clay soils in particular, changes in soil moisture content result in dimensional changes in the soil (Percival, 2004). Soil moisture content varies with season, and trees can add to this change (Roberts *et al.,* 2006). If the dimensional changes in the soil occur below the foundation level of buildings, this can result in subsidence damage. While both the intensity and frequency of shrink-swell soil hazards may increase with climate change, the spatial extent is unlikely to change (Forster and Culshaw, 2004).

A street tree survey in London revealed that about 5% of all trees removed in the previous five years were the result of subsidence claims, with some boroughs reporting losses of 10–40% (London Assembly, 2007). However, the perceived threat of subsidence may be much greater than the actual threat (GLA, 2005). Biddle (1998) has suggested that, while tree roots are involved in at least 80% of subsidence claims on shrinkable clay soils, even on clay soils the risk of a tree causing damage is less than 1%. In addition to the removal of trees, subsidence fears may also lead to the planting of smaller tree species (London Assembly, 2007). Given the importance of trees in the urban environment, a proper understanding is required of the mechanism of damage, how this can be prevented, and appropriate remedies if damage occurs (TDAG, 2008; Biddle, 1998).

10.3.2 Trees and air quality

As a result of their greater leaf areas and of the air turbulence created by their structure, trees and woodlands take up more gaseous pollutants, aerosols and particulates than shorter vegetation. While this can increase nitrogen and sulphur interception with effects on water quality (see preceding discussion), it can also improve air quality in urban areas (Beckett *et al.,* 2000). A number of UK studies have identified small potential decreases in urban air concentrations of NO_2, SO_2 and O_3 (e.g Broadmeadow and Freer-Smith, 1996) however, because of the known adverse effects of particulate pollution on human health, attention has recently focused on the uptake of particles by urban greenspace. Health benefits arising from improved urban air quality have been included as one of a number of the economic benefits of urban greenspace in the UK (Willis and Osman, 2005).

While all trees and woodland can improve air quality through the deposition of ozone, nitrogen dioxide, carbon monoxide, and nitric acid, certain tree species emit volatile organic compounds (VOCs), such as isoprene and monoterpenes. This can contribute to the formation of secondary pollutants such as ozone due to the reaction of VOCs and nitrogen oxides in the presence of sunlight (see Chapter 3). Donovan *et al.* (2005) have published a model which considers both pollutant uptake and VOC emissions and identifies the potential of different tree species to improve urban air quality.

10.3.3 Windthrow in storms

How wind patterns are likely to alter with climate change is poorly understood (Hulme *et al.,* 2002). Due to inconsistencies between models and the physical representation within them, the UKCIP02 climate scenarios were unable to attach any confidence level to the projections for wind speed and urged for caution in interpreting changes in wind speed (Hulme *et al.,* 2002). The UKCIP02 scenarios suggested little change in average spring and autumn wind speed and stronger winter winds in southern and central Britain.

In London, the vast majority of trees that have been removed in the last five years have been for health and safety reasons, including trees that have been damaged by storms and pose a risk from falling branches (Trees and Design Action Group, 2008). However, given that there is no robust understanding of wind speed changes with climate change, it may be most appropriate to follow existing guidance on planting and managing trees in urban environments.

10.4 Research priorities

- As the UK climate changes trees in cities and in urban greenspace will become increasingly important in managing temperatures, surface water and air quality. In the UK (and Europe) decision support systems are required to integrate understanding and to characterise the structure, function and economic benefits of urban and peri-urban trees and woodlands.
- It is important that trees and woodlands in urban areas are strategically planned and managed. Most UK local authorities lack the basic information on the nature and extent of trees and woodlands in their districts. This information gap needs to be addresses urgently and urban and peri-urban trees and woodlands should be included in national forest inventories.
- The interactions between interception of precipitation by trees, urban tree effects on soil infiltration and sustainable urban drainage need to be better understood. Information is required to identify the optimum tree and woodland component for the planning and design of green infrastructure, and planting along urban watercourses, on derelict and disused land (urban and peri-urban) requires more systematic consideration. The role of woodlands and forests in flood management requires further research but forests have an important role in the management of water resources.

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