Royal Horticultural Society

Sharing the best in Gardening

Gardening in a Changing Climate

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Gardening in a Changing Climate

**Eleanor Webster,
Ross Cameron and
Alastair Culham**

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Executive summary

Gardens can come in many forms, from a single container to a large domestic garden. They can be school, hospital or community gardens, or managed areas open to the public, such as components of urban parks, the grounds of stately homes or botanical gardens. They are multifunctional spaces, important for health and social well–being whilst also supporting the natural environment by helping to sustain wildlife. Gardens also provide important ecosystem services, such as mitigating urban flooding, urban cooling, building insulation, pollutant capture and carbon sequestration.

Since the 2002 publication of the 'Gardening in the Global Greenhouse' report, the climate has undergone dramatic change, with 2016 proving to be the warmest year on record (Met Office 2017; NASA 2017). The global climate is changing rapidly as a result of greenhouse gas emissions, and we are already experiencing the consequences of this, including more frequent and intense rainfall events in combination with rising temperatures. These changes will be compounded if human activities continue to emit carbon and other polluting compounds at the current rate. Despite this, there is a relentless trend to replace green space with impermeable surfaces, and burn fossil fuels to the extent where atmospheric pollutants are frequently reaching toxic concentrations in our increasingly urbanised world.

With populations rising and housing development set to continue into the future, the role of gardens in delivering the health and environmental ecosystem services formerly fulfilled by the natural environment will become increasingly important. With over half of UK adults engaged in gardening (Department for Culture Media and Sport 2015), there is great potential for this group to help maintain biodiversity, make a major contribution to reducing carbon dioxide emissions and prepare for the growing impacts of climate change.

In 2012, Defra released their first Climate Change Risk Assessment report, which was reviewed in 2017. The most recent report identified invasive organisms (including pests, diseases and invasive non–native species), resource use and soil health as key risks of climate change and highlighted the need for further research in these areas (Defra 2017). These risks align with those found by this report to be particularly relevant to gardeners, and are fundamental in underpinning scientific research at the RHS.

Gardens are important for many aspects of society, and their ubiquity means that they should be considered by policymakers, governments and NGOs who seek to mitigate the impacts of climate change and encourage adaptation at a national scale. This report has:

- Explored evidence that currently exists with regard to the intrinsic link between gardens and climate change.
- Summarised the implications of climate projections for gardeners.
- Outlined ways in which gardeners can both adapt to a changing climate, but also mitigate against further greenhouse gas emissions.

A summary of climate projections

- Global mean surface temperature has increased by 0.86˚C from 1880 to 2016 and is projected to continue to rise.
- The rate of future increase is dependent on the extent to which CO_2 and other greenhouse gas emissions are restricted in forthcoming years.
- Even with stricter legislation on greenhouse gas emissions, global temperature may still rise by at least a further 1.5 to 2.0°C over the next 100 years. Average temperature is projected to increase in all seasons and across all regions of the UK.
- There will continue to be high year on year variability in rainfall.
- It is likely that there will be an increase in the number of dry spells, and this will be most pronounced in southern areas of the UK, and especially over the summer months.
- The frequency of very wet days will increase over the winter, and this will be most pronounced in northern areas of the UK
- Gardens close to the coast or located near estuaries may experience more flooding as a result of an increase in the frequency and severity of tidal surges, whereas gardens located upstream will experience an increase in flooding due to more frequent and intense fluvial flooding events.
- It is theoretically possible that in the future, much of the UK could be frost free in some years.

Implications for gardeners

1. Warmer springs and autumns will extend the growing season and, therefore, some species will flower earlier and some will experience delayed leaf colouring or leaf fall. There will also be the need for more weeding, mowing and pruning.
2. A longer growing season might allow for a wider variety of plant species to be grown. When attempting to grow different varieties, gardeners will face a continual trade–off between a longer growing season and extreme weather events.
3. The amount of solar radiation available for plant growth has increased by around 5% relative to 1961–1990. This has been linked to a reduction in cloud cover.
4. Extreme rainfall events might increase the rate that nutrients, particularly nitrogen are washed out of the soil. Therefore, the timing of fertiliser application should be carefully considered.
5. Dry spells are projected to occur more often; therefore gardeners will need to consider methods of capturing water during intense rainfall events.
6. It is expected that warmer conditions will favour the spread of existing pests and diseases, in addition to aiding the establishment of new cases. However, climate change will mean that populations of those pests and diseases who exploit frost wounds, for example, may struggle to survive.

7. Even if greenhouse gas emissions are reduced today, the climate will continue to change rapidly over the coming decades due to historic emissions. Consequently, gardeners should be mindful that trees planted now might not be suited to the climate in 2050, for example.

What can you do?

1. **Green your living space.** Trees and plants remove heat–trapping CO_2 from the atmosphere, reduce the risk of flooding, and some species can even capture particulate pollution.
2. **Plant a diverse range of plants in your garden.** Earlier flowering might disrupt host–pollinator associations, so plant a diverse variety of pollinator friendly plants with different flowering times.
3. **Adopt new ways of growing.** Green roofs and walls can result in year–round home energy savings due to a cooling effect in summer and an insulating effect in winter. Improve energy efficiency through use of technologies and try to reduce the use of petrol–powered tools.
4. **Water use and management in gardens.** Seek water butts with a larger than standard capacity to ensure a sufficient water supply over the summer. Select plants and design strategies better suited to the environment.
5. **Avoid peat.** Peatlands store considerable amounts of carbon. Look, ask for and use peat–free composts. There are now some high quality products out there that work.
6. **Compost your garden and kitchen waste.** Gardeners may wish to compost more garden and kitchen waste as this provides excellent nutrients for the garden, but thrown away as household waste, it ends up on landfill and produces potent greenhouse gases.
7. **Adopt the 4R's. Reduce** – the use of resources in your garden wherever possible, **Reuse** – household materials and seasonal items year on year, **Recycle** – your garden waste, plastic, glass and metals and **Reinvest** – help stimulate demand for recycled products by buying recycled items.
8. **Avoid wherever possible the use of chemicals in your garden.** As a first choice avoid the use of chemicals in the garden. If required, use products with a low carbon footprint.
9. **Practice Integrated Pest Management (IPM).** Adopt a combination of good plant biosecurity, biological, cultural and chemical controls in order to minimise the spread of pests and diseases.
10. **Invasive Species.** Gardeners should ensure that their cultivated plants remain in the garden, and that legislation is adhered to during plant disposal.

Preface

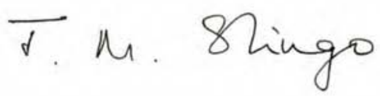
Slingo, J

Climate change is likely to be one of the defining challenges of the 21st century and how we respond will determine our future prosperity, health and well–being and the sustainability of Earth's natural environment. This report is a timely reminder of how much the UK's climate and the gardens that we prize so greatly are already being affected by human emissions of greenhouse gases.

In Paris in 2015 over 190 nations agreed to act to limit the increase in Earth's surface temperature to less than 2ºC and preferably to 1.5ºC if at all possible. Future generations may well look back on 2015 as the turning point in the acceptance of climate change and the need to act. But achieving this goal will not be easy and we know that we are already committed to some level of climate change. So the future can look daunting; but as this report shows, there are many things that we, as gardeners, can contribute.

Gardens can help in so many ways; by helping to reduce our emissions and store more carbon, by providing safe havens for our wildlife, by contributing to a more comfortable and safer local environment. With more and more of us living in cities, the importance of access to green spaces and gardens can only grow and become increasingly vital for our health and well–being.

But as this report makes clear, our perspectives on what a garden should be and what we might like to grow in it will have to change. The good news is that we now have a pretty fair idea, thanks to climate science, of what our future weather and climate might be like. That means that we can start to plan now for the changes that we will need to introduce in our gardens. This report provides some valuable guidance, and demonstrates how climate change need not be a disaster for our gardens, but instead provide us with a wealth of opportunities.



Professor Dame Julia Slingo OBE
Former Met Office Chief Scientist, and
member of the RHS Science Committee

1. Introduction

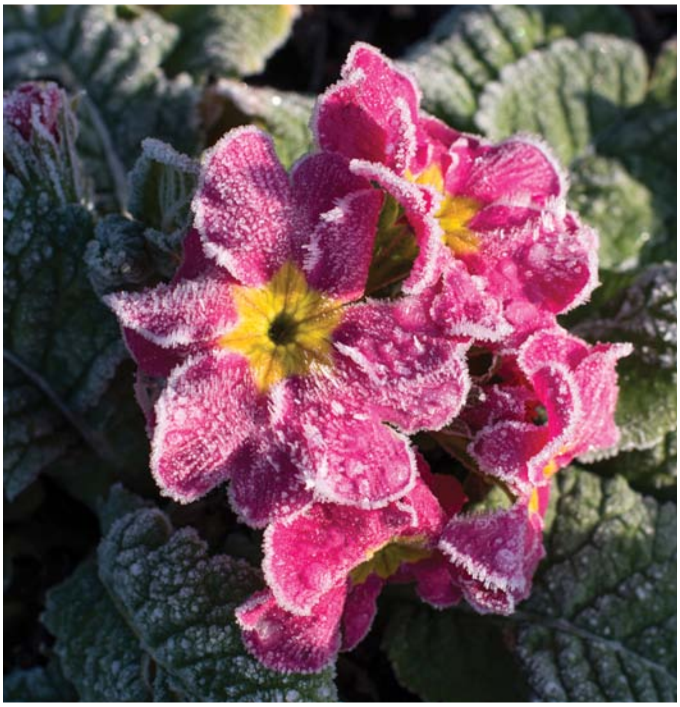
Jeff Morgan / Alamy

In 2002 UKCIP published the Gardening in the Global Greenhouse report, which was supported by a wide range of organisations, including the RHS. At the time, while climate change had been acknowledged since the 1980s, its impact and prospects for future change had not been assessed or presented to the gardening public. The 2002 report provided a remarkable summary of current knowledge and discussed the likely consequences for horticulture and gardening. However, even in 2002, the prospect of climate change having a real influence on people's lives and how they garden was not considered. Climate models, which were the best available at the time, suggested that gardening in the UK would be about warmer, possibly frost–free weather, with drier summers and slightly wetter winters. For many, the prospect was one to be looked forward to, with the possibility of growing a wider array of exotic and unusual plants. However, some of our more traditional fruit crops would be less likely to thrive in the changed climate – but that would be offset by the greater success with plants such as grape vines and olives.

The Intergovernmental Panel on Climate Change published its fifth report (AR5) in 2013, which addressed the physical basis of climate change. A point that is emphasised now is the role of the oceans as a buffer for climate change but, as with all buffers, with limited capacity. The evidence for this is the increasing acidification of the oceans as they absorb rising levels of carbon dioxide (CO_2). The role of the oceans also underlines the reason why, even if there were a rapid reduction in the levels of greenhouse gases, the effects of climate change are expected to continue not just through the present century but on into the next and possibly far beyond. In the last decade, the world has followed the highest emissions scenario, indicating that more needs to be done to slow down the rate of greenhouse gas emissions from humans. The winter of 2015 was the warmest experienced in the UK since records began, and was the second wettest winter after 2013/14. During both winters, severe storms caused widespread damage to landscape and infrastructure, leaving some areas under water for weeks on end.

It is not the purpose of this report to explore the possible causes of climate change, however there is no doubt that there is a change taking place in our climate. Rather, our aim is to use recent UK climate change projections to establish the consequences for gardening and horticulture more definitely.

Gardens are not isolated entities. They exist in a wider landscape and comprise an element of that environment. As such, as climate change causes the environment to change, that has an effect on people, plants and gardens; with gardeners themselves being potential agents of change that affect the wider environment and society. Preliminary evidence from the survey in Chapter 4 tells us



RHS / Anna Brockman

that amateur and professional gardeners are already experiencing climate change, and what their concerns are for the future. Further, there is concern in relation to an increase in the rate of occurrence of new pests and diseases in the UK. The movement of plants for commercial or ornamental purposes presents a real threat to our native and garden plants, a threat that is likely to be increased by climate change. The spread of pests and diseases is part of a wider issue of what are known as invasive non–native species. Horticulture is frequently seen as the major pathway for the introduction of these species and there is concern about garden plants that escape, as some species that formerly would not establish in the wider environment now seem to have established and some also seem to be spreading. These issues mean that an evaluation of the impact of climate change is now a part of any risk assessment for a pest, disease or a potentially invasive species. These are now given greater emphasis by legislative developments in the UK and Europe, setting new regimes for the management of non–native invasive species and pests and diseases. This, and other examples of interactions between the garden and natural environment are discussed in Chapter 5.

One of the most frequent observations made by gardeners is the timing of plant development through the year, from the date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RHS / Tim Sandall

of first emergence of leaves, or flowers, to when leaves begin to colour and fall, and the practical consideration of when people start and stop mowing their lawns. The timing of these events is intrinsically linked to climate change, and since the last report a considerable amount of data has been gathered and analysed, which is summarised in Chapter 6.

It has been a sobering experience to discover, in the course of the preparation of this report, just how much work has been done in the UK and elsewhere to evaluate the likely path of climate change and its consequences for many aspects of our lives. People are becoming increasingly empowered to minimise their contribution to climate change, such as the use of solar panels. The collective impact of such environmentally conscious choices can be profound both economically and environmentally, as evidenced by the fact that in 2015, 50% of the UK's energy was from clean sources (DECC 2016). As discussed in Chapter 7, gardens can be managed to help ease climate change and support the surrounding ecosystem. The collective impact of such management practices could be startling, since gardening is a free–time activity for 50% of the UK population (Department for Culture Media and Sport 2015), and gardens occupy around 4500 km^2 of land area (Davies et al. 2009). In addition, gardening activities support a horticultural industry worth an estimated £13 billion (Ornamental Horticulture Roundtable 2015), therefore, environmentally mindful gardening practice is likely to be an advantage economically as well as environmentally.

2. Climate change: the global perspective

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Maskell, K

The climate of the Earth has varied naturally in the past over a whole range of timescales. For example, the Earth's climate has varied between cold glacial and warm inter–glacial conditions over periods of many thousands of years. On timescales of a few years, we see periodic warming events in the tropical Pacific Ocean (known as El Niño). However, there is now a large and robust body of evidence, which shows that human activity is altering our climate on a global scale, mainly as a result of the release of carbon dioxide from fossil fuel combustion and other activities since the industrial revolution. This human influence is now affecting our climate, in addition to the natural factors that have always been at play.

In this Chapter we summarise evidence on human–induced climate change, looking first at observations of how climate has changed, then the reasons for these changes and finally going on to look at what this means for the future. We concentrate on a global perspective here in order to put into context the information about how UK climate is changing (covered in Chapter 3).

Climate is usually defined as the average (mean) conditions experienced at a location, over a region or over the globe as a whole, defined in terms of temperature, rainfall, wind etc. and typically averaged over a 30 year period. Climate change refers to a change in these average conditions, which persists for an extended period (typically decades or longer). Weather, on the other hand, usually refers to the conditions occurring on shorter timescales (days and weeks) at a specific time and place.

The information in this Chapter is based primarily on the most recent report from the Intergovernmental Panel on Climate Change (IPCC). The IPCC was established by the World Meteorological Organization and the United Nations Environment Program in 1988 in order to assess scientific information on climate change and to publish assessment reports that summarise the state of the science. Note that in IPCC reports, climate change is a combination of both natural and human–induced factors. In other documentation, the term climate change is sometimes used to refer specifically to human–induced change (e.g. in the United Nations Framework Convention on Climate Change).

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2. Climate change: the global perspective

2.1 Changes in the global climate system

There have been extensive analyses of a whole host of observations of the climate system in order to assess how climate has changed since pre–industrial times and (where observations exist) over longer periods. Many aspects of the climate system have been looked at, such as: the land surface, the atmosphere, the oceans and snow and ice. Taken together these analyses provide unequivocal evidence that the climate has warmed over the last 150 years and that many other aspects of climate have also changed. In this section we describe the key observations that have been analysed.

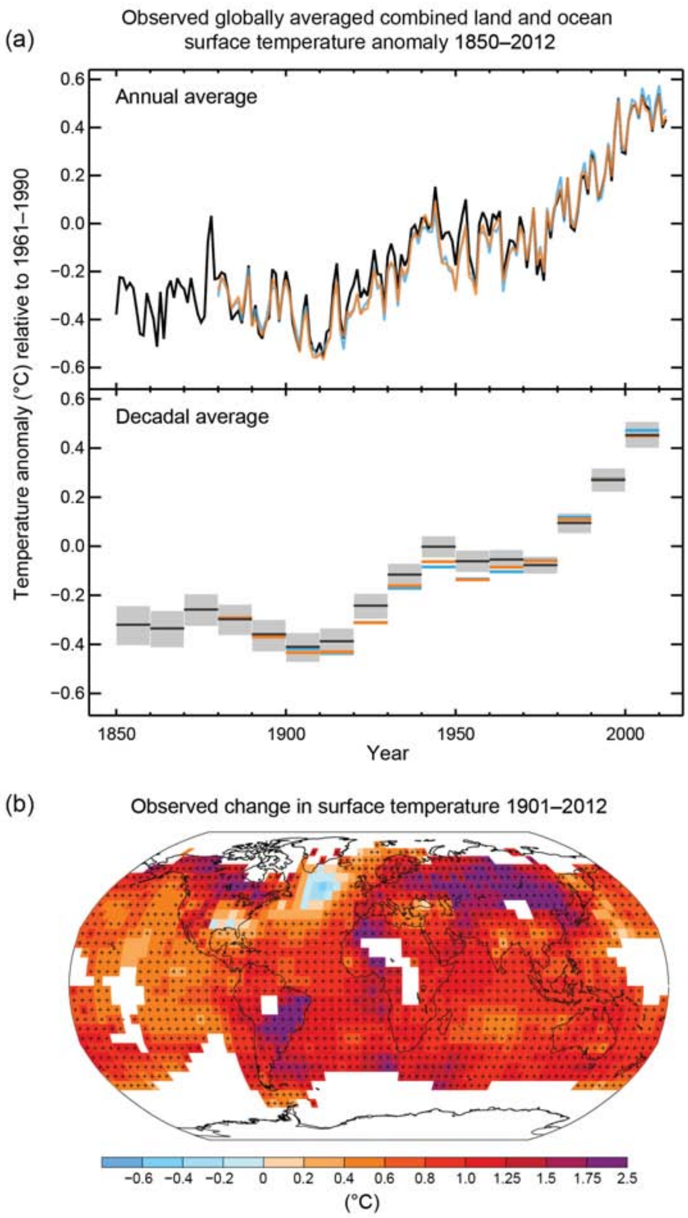


Figure 2.1: (a) Observed global mean surface temperature over the period 1850–2012 expressed relative to mean temperatures over the period 1961–90. Upper panel shows annual mean values (from three different temperature datasets) and lower panel shows decadal mean values with estimated uncertainty (grey shading). (b) Map of observed surface temperature change from 1901 to 2012. Source: IPCC (2013).

Global mean surface temperature has increased by 0.85°C between 1880 and 2012 with warming observed over almost the entire world (Fig. 2.1b). Warming has not been steady, there have been periods of faster warming and periods of slower warming (Fig. 2.1a). The year 2015 saw exceptional warmth, and global temperatures exceeded the average for the mid–to late 19th century (commonly considered to be representative of pre–industrial conditions) by 1°C for the first time (Blunden et al. 2016).

Direct temperature measurements with coverage substantial enough to estimate global scale climate only exist for the last 150 years or so. Temperatures before that period can be estimated from "proxy" data such as tree rings and this helps to put the recent warming into context. Figure 2.2 shows Northern Hemisphere temperature since 700 AD reconstructed from a range of proxy records and indicates that the temperatures of the late 20th Century were unusually warm (Jansen et al. 2007). Other analyses (IPCC 2013) show that the last three decades have probably been the warmest 30 year period in the last 1400 years.

2.1.1 The interaction between the atmosphere and the ocean

Over 90% of excess heat energy that has accumulated in the climate system since pre–industrial times is stored in the ocean. Consequently, observations of ocean temperatures show that the upper level of the oceans (above 700 m) has been warming since the 1870s. There is also evidence of warming at deeper levels in the ocean, although data are scarce. Changes in the temperature of both the surface and deep layers alters ocean stratification, thereby affecting ocean currents that are often important for controlling weather systems. Also, rising temperatures causes water to expand, thus thermal expansion of the oceans accounts for a proportion of observed sea level rise (Rhein et al. 2013).

Global mean sea level has risen by 0.19 m (range 0.17 to 0.21) over the period 1901 to 2010, largely due to thermal expansion of the oceans, with smaller contributions from melting ice sheets and glaciers. Sea level rise has accelerated in recent decades, although a period of more rapid sea level rise also occurred between 1920 and 1950. The rate of sea level rise since the mid–19th century was larger than the mean rate during the previous two thousand years.

The Earth's oceans have also become more acidic as a result of increasing carbon dioxide (CO_2) in the atmosphere, some of which is absorbed by the ocean. The pH of ocean surface water has decreased since the beginning of the industrial era, corresponding to a 26% increase in acidity. Ocean acidification is expected to make it harder for calcifying organisms such as oysters, clams, some corals, and calcareous plankton to produce and maintain their shells. The exchange of carbon dioxide between the atmosphere and ocean is complex. So far, the absorption of atmospheric carbon dioxide by the oceans has been critical in offsetting greenhouse gas emissions. However, the rate at which the ocean will be able to continue absorbing carbon dioxide remains uncertain.

Changes in the Earth's cryosphere (ice and snow) are also indicative of a warming world. Since 1979 Arctic sea ice extent has decreased in all seasons, but most rapidly in summer and autumn. During the period between 1979 and 2012, summer minimum sea ice extent decreased by approximately 11% per decade (note that robust observations of sea ice extent are available from satellites since 1979). The Greenland and Antarctic ice sheets are currently shrinking and the rate of ice loss has increased substantially over the last 20 years (the period for which data are available). For example, between 1999 and 2001 the Greenland ice sheet lost on average 34 Gigatonnes (Gt) of ice per year. Over the period 2003 to 2012 the average rate was 215 Gt per year. The ice losses from the Antarctic are currently limited to the western edge, while ice loss is occurring across the entire Greenland ice sheet (Fig. 2.3, top panel).

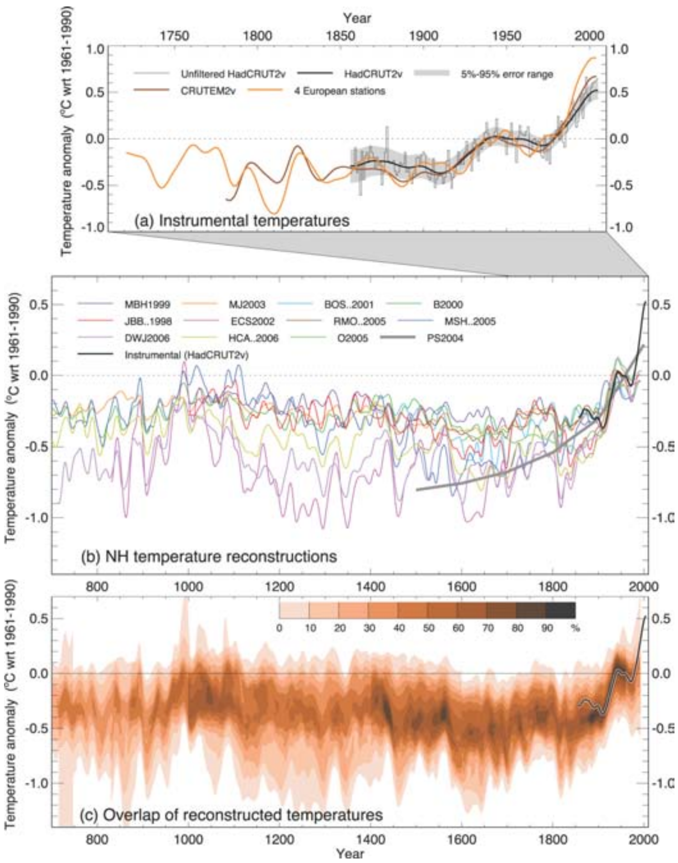


Figure 2.2: Northern Hemisphere temperature variation: (**Top panel**) over the period with direct instrumental records from thermometers, (**Middle panel**) since 700 AD reconstructed from multiple climate proxy records (derived from sources such as tree rings and corals) and (**Bottom panel**) the agreement between different proxy records. The orange shades indicate the level of agreement (darker colours indicate higher agreement). The instrumental temperature record is shown in black. All series have been smoothed to remove fluctuations on time scales less than 30 years. All temperatures represent anomalies (°C) from the 1961 to 1990 mean. Source: Jansen et al. (2007).

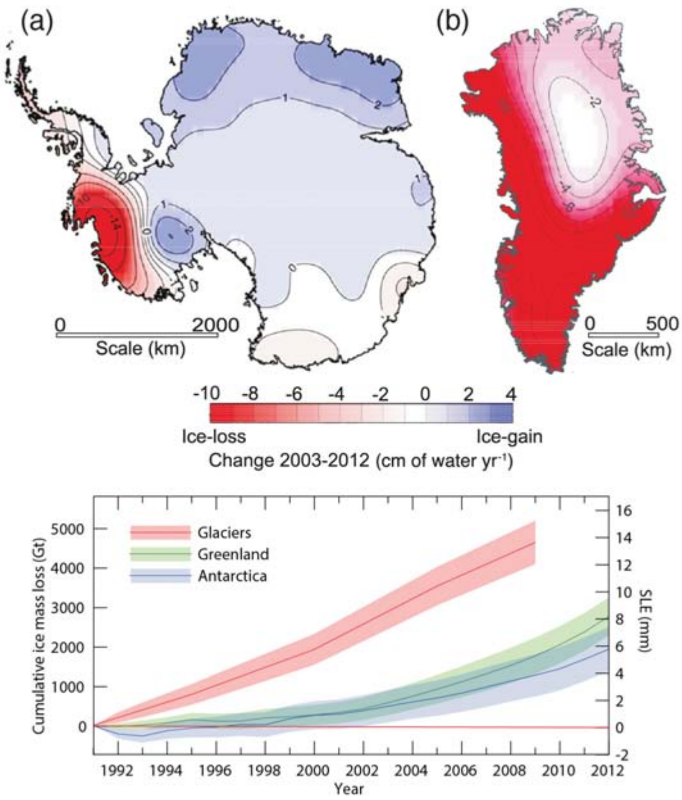
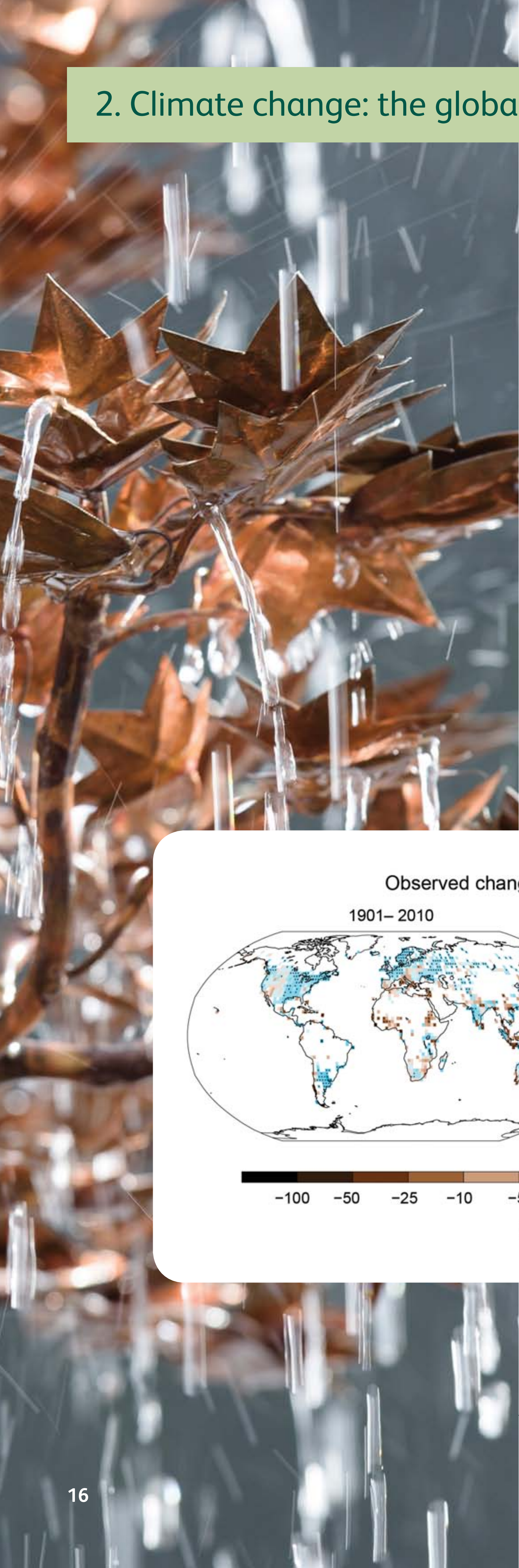


Figure 2.3: (**Top panel**) Ice loss/gain from (a) Antarctica and (b) Greenland, shown in centimetres of water per year for the period 2003–2012. (**Bottom panel**) The assessment of the total loss of ice from glaciers and ice sheets in terms of mass (Gt) and sea level equivalent (mm). The contribution from glaciers excludes those on the periphery of the ice sheets. Source: Stocker et al. (2013).



2. Climate change: the global perspective

As illustrated in Fig. 2.4, precipitation (rain, sleet, snow etc.) has increased since 1951 over large parts of the Northern Hemisphere land surface, and has probably been increasing since 1901, although it is difficult to determine long term trends as there are relatively few observations of precipitation pre–1901. In the Southern Hemisphere regions of increasing and decreasing rainfall are seen over the period 1951 to 2010 (data before 1951 is very scarce).

A number of climate extremes have also changed over the 20th century. The length and frequency of warm spells, including heat waves, has increased across the globe since the middle of the 20th century, with the most noticeable changes occurring in large parts of Europe, Asia and Australia. The number of cold days and nights has decreased, whereas warm days and nights have increased on a global scale. Over some land areas, most notably over North America and Europe, heavy rainfall events have increased in frequency and/or intensity since around 1950.

Collectively, observations summarised in this section provide unequivocal evidence that the world has warmed since pre–industrial times. There is also evidence to suggest that the current warm conditions are unusual and that a range of other aspects of climate have also changed.

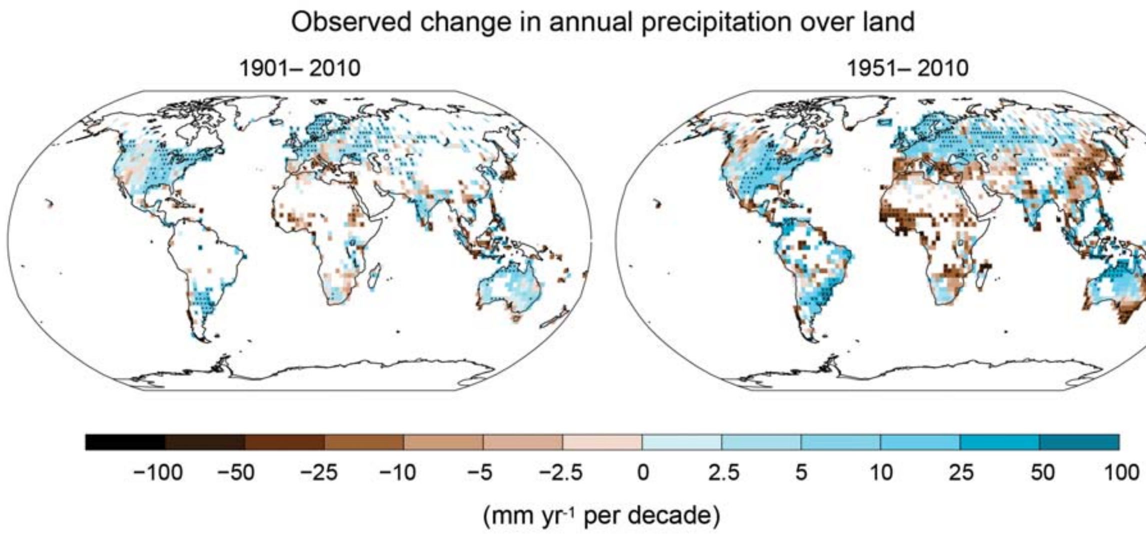


Figure 2.4: Observed change in precipitation over land between 1901–2010 and 1951–2010. Source: IPCC (2013).

2.2 Causes of Climate Change

In simplified terms, the temperature of the Earth is controlled by the balance between incoming energy from the Sun and the energy being emitted by the Earth. If "energy in" is balanced by "energy out", then global temperatures will be reasonably stable. However, if the balance is disrupted, then the Earth's temperature will change until a balance is reached.

Many natural factors can change the energy balance of the climate system. For example, the energy received from the Sun varies over annual, decadal and millennial cycles and an increase in energy from the Sun has a warming effect on the Earth. Volcanic eruptions can inject particles into the atmosphere that reflect the Sun's radiation back into space, thereby reducing the amount of energy entering the climate system. The net result is a cooling effect on the climate.

In reality of course the picture is more complex and natural variations in climate can be experienced due to a redistribution of energy between components of the climate system, most commonly between the atmosphere and oceans. For example, the El Niño phenomenon, which sees a warming of the tropical Pacific Ocean every 3 to 5 years, is the result of a release of stored energy from within the ocean.

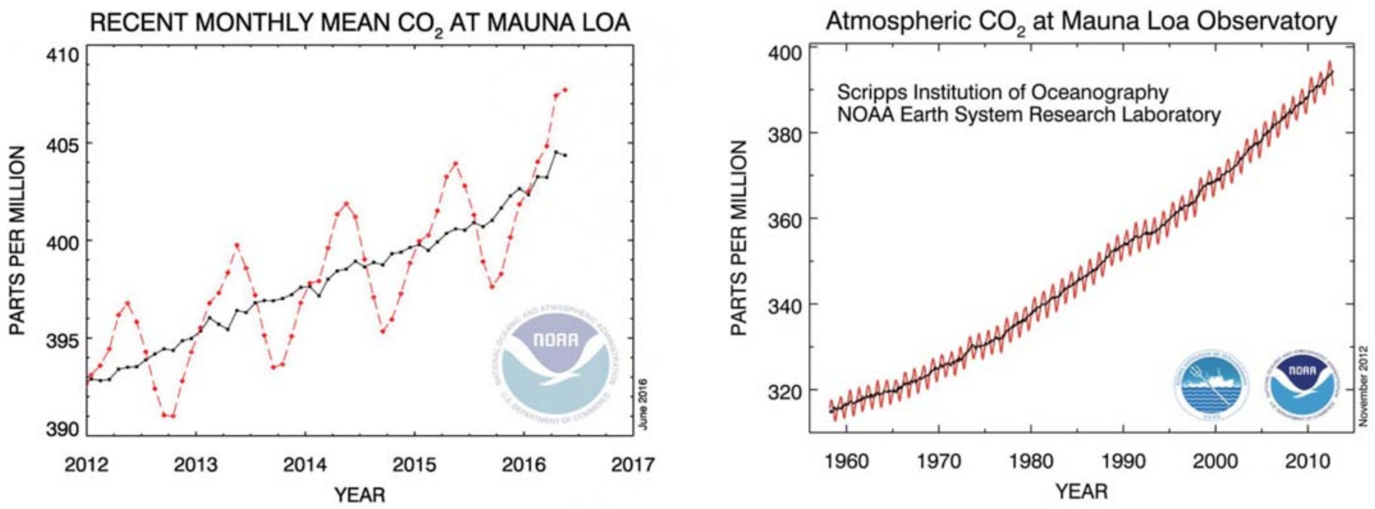


Figure 2.5: (**Left**) Recent monthly mean atmospheric CO_2 concentration at Mauna Loa for 2012 to 2016. Dashed red line indicates mean monthly values and the black line is the overall trend. (**Right**) Monthly mean CO_2 for Mauna Loa since the start of recording in 1958. Red and black lines same as for previous image. Source: National Oceanic and Atmospheric Administration (2016).

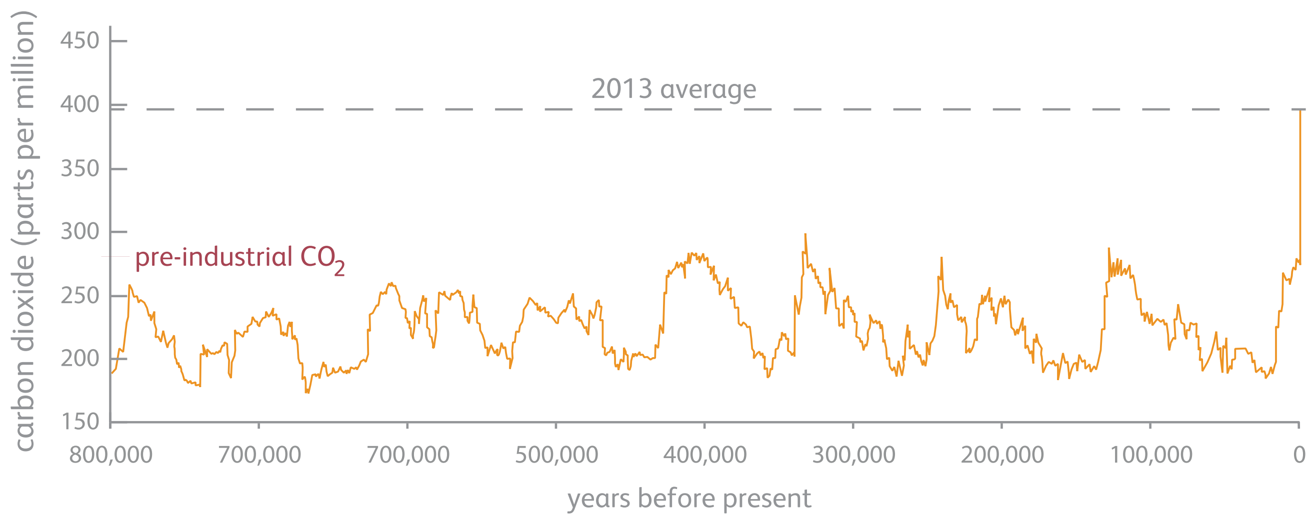


Figure 2.6: Atmospheric carbon dioxide concentrations in parts per million for the past 800,000 years, with the 2013 annual average concentration as a dashed line. The peaks and troughs in carbon dioxide levels follow the coming and going of ice ages (low CO_2) and warmer inter–glacial periods (higher CO_2). Source: Graph by NOAA Climate.gov, based on data from Lüthi et al. (2008), provided by NOAA NCDC Paleoclimatology Program (Blunden 2014).

2. Climate change: the global perspective

Human activity can also alter the energy balance of the climate system. An increase of greenhouse gases in the atmosphere reduces the amount of energy emitted by the Earth, so "energy out" becomes lower than "energy in". Since the industrial revolution, human activity, particularly the burning of fossil fuels, has increased the concentration of greenhouse gases in the atmosphere. The greenhouse gases being altered most by human activity are: carbon dioxide (CO_2), methane (CH_4), halocarbons (chlorine and fluorine containing chemicals) and nitrous oxide (N_2O).

The amount of carbon dioxide in the atmosphere has increased by over 40 % since the pre–industrial era: from 278 ppm[1] in 1750 to 315 ppm in the 1950s to over 400 ppm in 2016 (Fig. 2.5). Methane and nitrous oxide have increased by 150 % and 20 % respectively since the pre–industrial era (from 1750 to 2011). Data derived from bubbles of air trapped in ice cores from Greenland and Antarctica show that concentrations of carbon dioxide (CO_2) (shown in Fig. 2.6), methane (CH_4) and nitrous oxide (N_2O) are now substantially higher than at any time in at least the last 800,000 years.

Most carbon dioxide emissions produced by human activities are linked to fossil fuel combustion, cement production and, to a lesser extent, deforestation and land–use change. Since pre–industrial times, just under two thirds of carbon dioxide emissions have been removed from the atmosphere and stored by the land and the ocean, the remainder stayed in the atmosphere causing the observed increase in concentration.

Human activity is also increasing the concentration of aerosols (small particles or liquid droplets) in the atmosphere, which can also affect climate. Aerosols are produced from burning tropical forests and other sources, but the major component comes in the form of sulphate aerosols created by the burning of coal and oil.

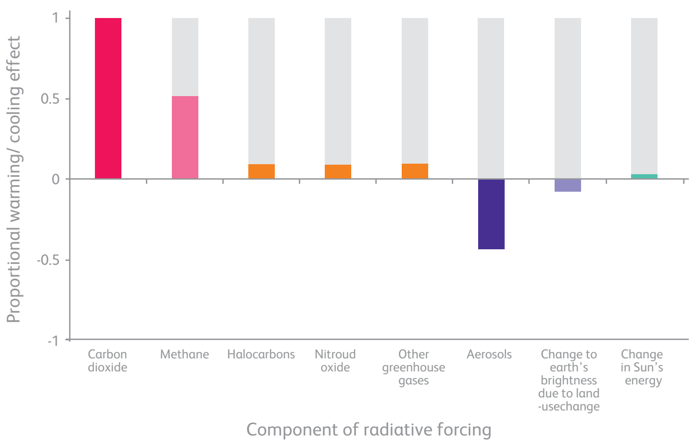


Figure 2.7: Proportional warming/cooling effect of increasing greenhouse gases, aerosols and changes in the Sun's energy since pre–industrial times. A positive value (red/orange) is a warming effect, and a negative value (blue) represents a cooling effect. Data adapted from Myhre et al., (2013).

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Aerosols produced from human activity (such as pollution from cars and factories) typically have a cooling effect on climate because they reflect sunlight back to space. However, some aerosols, such as black carbon, can have a warming effect on climate. Note that aerosols can also be produced naturally, for example from volcanic eruptions and desert dust storms.

The warming effect of the increase in greenhouse gases since 1750 dominates over any natural influences on climate over the same period (Fig. 2.7). The increase in aerosols due to human activity has created a cooling effect that offsets some, but not all of the warming due to greenhouse gases. Since 1750, the change in energy from the Sun has produced a very small warming effect, much smaller than the warming effect of increasing greenhouse gases.

Looking at all the evidence, the latest IPCC report (2013) concludes: "It is extremely likely that human influence has been the dominant cause of the observed warming since the mid–20th century." It is also very likely that human influence has contributed to observed global scale changes in the frequency and intensity of daily temperature extremes since the mid–20th century, and likely that human influence has more than doubled the probability of

[1] ppm stands for parts per million: the number of CO_2 molecules in 1 million molecules of (dry) air. For example, 372 parts per million of CO_2 (abbreviated as ppm) means that in every million molecules of (dry) air there are on average 372 CO_2 molecules.

occurrence of heat waves in some locations. Human activity may also be contributing to global scale changes in precipitation and to the observed increase in the frequency and intensity of heavy rainfall over many land areas.

2.3 Projections of future climate

2.3.1 Simulating the global climate system

In order to explore what might happen in the future, it is necessary to make assumptions about possible changes in emissions of greenhouse gases and other pollutants from human activity that can cause climate change. Future emissions depend on many social and economic factors such as population growth, technology and energy use, economic growth, development and land–use change. International and national action to control emissions of greenhouse gases will also affect future emissions. It is impossible to predict exactly how such factors will change, so typically a number of scenarios are used to span a wide range of plausible future greenhouse gas emissions. IPCC WG1 AR5 report (2013) uses 4 scenarios (known in the IPCC report as Representative Concentration Pathways or RCPs, see Fig. 2.8):

RCP2.6. LOW emissions – assumes actions across the world to rapidly and significantly reduce global greenhouse gas emissions

RCP4.5. MEDIUM LOW emissions – moderate reductions in greenhouse gases over 21st century

RCP6.0. MEDIUM HIGH emissions – continued growth in emissions followed by moderate reductions.

RCP8.5. HIGH emissions – assumes global greenhouse gas emissions continue to grow rapidly through most of the 21st century

Scientists use complex models of the climate system to predict what might happen to climate in the future and to understand more about the processes at work in the climate system. Climate models are huge computer programmes, which simulate the

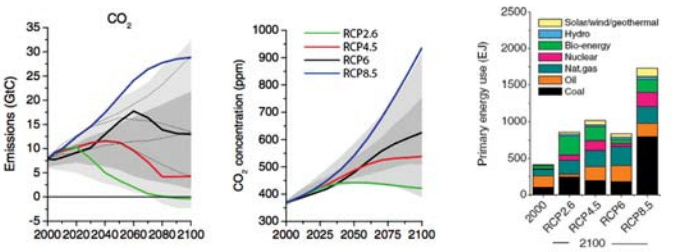

Figure 2.8: (**Left**) Emissions of CO_2 across RCPs, (**Middle**) trends in concentrations of CO_2. Grey represents the area of uncertainty, dotted lines are an aretefact of the baseline scenarios used in the calculation of RCPs. (**Right**) Energy sources by sector. Source: van Vuuren et al. (2011).

atmosphere, ocean, land surface and ice, and the interactions between them. The computer programme represents the climate in terms of key quantities such as atmospheric temperature, pressure, wind, and humidity at locations on a three dimensional grid. The atmospheric grid covers the Earth's surface and extends from the surface to the upper atmosphere. A similar grid for the ocean extends from the ocean's surface to the ocean floor. By solving the relevant mathematical equations the computer is able to calculate how the state of the atmosphere and ocean evolves in time. A typical global climate model currently has grid boxes with horizontal dimensions of approximately 100–200 km; this is known as the "spatial resolution". Next generation models, however, will have significantly smaller grid cells.

Climate models are compared with observations to assess their reliability and to identify where improvements are needed. They are not perfect representations of the climate system, but they are capable of simulating its large–scale features and responding realistically to changes such as a volcanic eruption. Simulating and predicting local climate is something that stretches the capability of current climate models. This is because the grid boxes into which the land, atmosphere and ocean are divided are relatively large; typically around 200 km by 200 km. Global climate models of a higher spatial resolution are being developed, but these require a much greater degree of computational power than coarser resolution models. See further discussion about UK climate change in Chapter 3.

2.3.2 Future climate change

Further warming as a consequence of past greenhouse gas emissions is unavoidable. It is likely that global mean surface temperature for 2017 to 2035 will be 0.3 to 0.7°C above the 1986 to 2005 average. 2016 was a record–breaking year, as the six month period (January to June) was the warmest half–year on record (NASA 2016). Volcanic eruptions, land–use changes, emissions of aerosols from human activity and natural variability would all affect the level of warming, particularly at regional and local scales.

Over the next few decades, the frequency of warm days and warm nights is likely to increase in most land regions, while the frequency of cold days and cold nights will decrease. Models also project increases in the duration, intensity and spatial extent of heat waves and warm spells for the near–term (i.e. months, seasons).

Near–term changes in precipitation at regional scales will be strongly influenced by both natural variability and emissions of aerosols from human activity. However, it is likely that the frequency and intensity of heavy precipitation events will increase over land, although details will vary from place to place. Near–term changes in climate and their implications for the UK are discussed in more detail in Chapter 3.

Looking to the end of the 21st century, global mean surface temperature is likely to be 0.3°C to 1.7°C warmer than during the period 1850 to 1900 under RCP2.6 (low scenario). Global temperatures are likely to rise by between 1.4°C and 3.1°C under the RCP6.0 (medium–high) scenario, and by 2.6°C to 4.8°C for the RCP8.5 (high) scenario (Fig. 2.9). Warming will not be steady, there will be periods of faster warming and periods of slower warming, and warming will continue beyond 2100 under all RCP scenarios except RCP2.6. The Arctic region will warm more rapidly than the global average, and warming over land will be greater than over the ocean (Fig. 2.10).

Increases in the frequency, duration and magnitude of hot extremes (from days to seasons) are expected; however, occasional cold winter extremes will also occur. Under the high emissions scenario (RCP8.5) it is likely that, in most land regions, a current 20–year high–temperature event will occur more frequently by the end of the 21st century (at least doubling its frequency, but in many regions becoming annual or biannual).

In the long–term, global mean precipitation is expected to increase (by an estimated 0.5 % to 4 % per °C of warming), but some regions will see increasing rainfall while others will see less rainfall (Fig. 2.10), and these trends in some places will vary between seasons. It is likely that there will be greater contrast between wet and dry regions and between wet and dry seasons, although local details are uncertain. Extreme precipitation events over most of the mid–latitude land masses and over wet tropical regions will very likely become more intense and more frequent by the end of this century, as global mean surface temperature increases.

A large fraction of human–induced climate change from the emissions of carbon dioxide would take hundreds to thousands of years to reverse. Even if all human emissions of carbon dioxide ceased immediately, surface temperatures would remain approximately constant at elevated levels for many centuries. Due to the long timescales of heat transfer from the ocean surface to depth, ocean warming will continue for centuries. Depending on the scenario, about 15 to 40 % of emitted carbon dioxide will remain in the atmosphere longer than 1,000 years.

Global mean sea level will continue to rise through the 21st century at a rate that is very likely to exceed recent observed rates of rise (over 1971–2010). By 2100 global mean sea level could be 20 cm to 1 m higher than over the period 1986–2005 (Fig. 2.11). For all RCP scenarios, thermal expansion of the oceans in response to warming is the largest contribution to sea level rise, accounting for about 30 to 55 % of the total; glaciers are the next largest, accounting for 15–35 % and the remainder from the Greenland and Antarctic ice sheets. Sea level rise will not be uniform across the world's oceans and coastlines, currently the regional pattern of sea level rise is very uncertain.

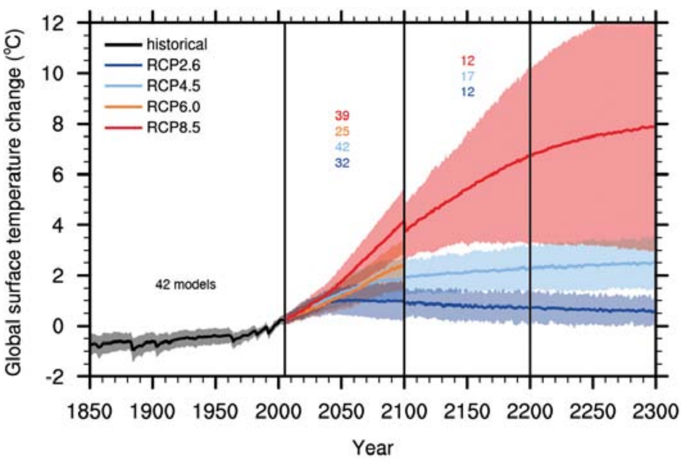

Figure 2.9: Time series of deviations in global annual mean surface air temperature (relative to 1986–2005). Solid lines represent the average (mean) of the output from multiple models, and the shading represents the range of model outputs. Discontinuities at 2100 are due to different numbers of models performing the runs beyond the 21st century and have no physical meaning. Source: Collins et al. (2013).

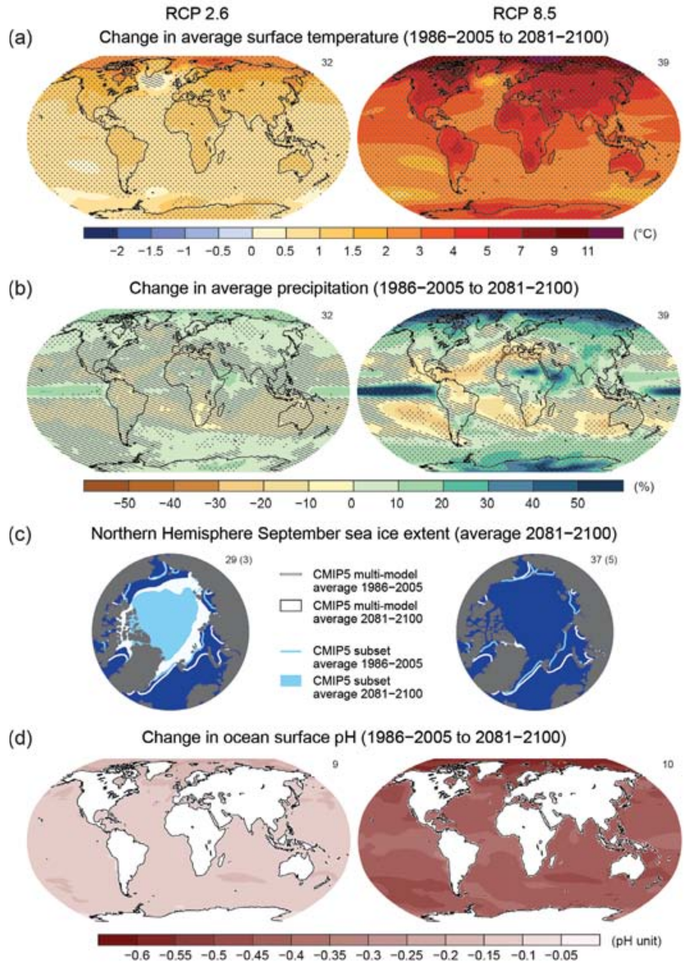

Figure 2.10: Maps showing the results generated from multiple model outputs. Changes are relative to the period 1986–2005. (a) Annual mean surface temperature change, (b) average per cent change in mean annual precipitation, (c) projection for Northern Hemisphere September sea ice extent (trend of the Arctic sea ice extent is given in light blue colour) and (d) change in ocean surface pH. Source: (IPCC 2013).

It is virtually certain that global mean sea level will continue to rise beyond 2100. By 2300 for example, sea level could rise by between 1 to 3 m (relative to pre–industrial levels) for a "high emissions" scenario (consistent with RCP8.5). For a low emissions scenario (consistent with RCP2.6), sea levels are estimated to rise by less than 1 m by 2300.

For a global mean temperature rise estimated at 1 to 4°C, studies suggest a near complete loss of the Greenland ice sheet over a period of more than 1000 years, which would raise sea level by about 7 m. If temperatures were to drop in that time, the ice sheet might regrow, although some permanent loss of ice mass might be inevitable. Parts of the West Antarctic Ice sheet, with enough ice to raise sea level by about 3 m, may also be vulnerable to rapid and irreversible ice loss.

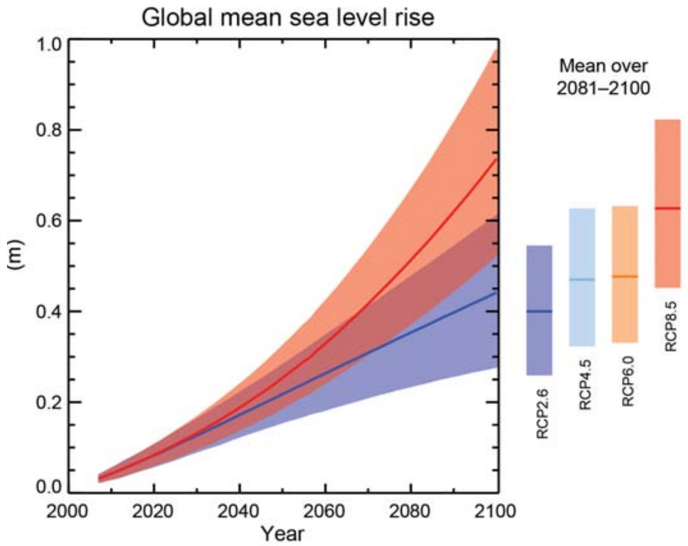

Figure 2.11: Projections of global mean sea level rise over the 21st century relative to 1986–2005 from a combination of several models. The range of the mean output from the models over the period 2081–2100 are given as coloured vertical bars. Source: IPCC (2013).

2.4 Global action to address human–induced climate change

We saw in Section 2.3 that if emissions of greenhouse gases continue to grow rapidly, global temperature could rise by 4°C or more by the end of the 21st century with associated changes in rainfall and weather extremes. Such changes in climate are likely to have serious impacts on water availability, food security, human well–being and the natural environment (IPCC 2014b).

At the United Nations Earth Summit in 1992, the United Nations Framework Convention on Climate Change was agreed (hereafter referred to as "the Convention") which acknowledges the risks from climate change and aims to: "… stabilise greenhouse gases in the atmosphere at a level that prevents dangerous anthropogenic interference with the climate system" (UNFCCC 2014a). Following major climate negotiations in Paris in December 2015, countries around the world have now agreed to limit warming globally to well below 2°C above pre–industrial (as of 2012, global temperature had already risen by 0.85°C above pre–industrial levels). A warming across the globe of 2°C above pre–industrial levels will limit the impacts of climate change, but will not avoid the impacts altogether. It is possible to meet this target if global greenhouse gas emissions peak in 2020, followed by reductions of around 4% per year (Met Office 2013b). This will require major, but achievable, technological and institutional changes across all sectors of the global economy, including the up–scaling of low and zero carbon energy. Member Parties of the recently ratified Paris Agreement will be obliged to put forward their best efforts to achieve this through "nationally determined contributions". Parties will be required to report regularly their emissions and implementation efforts with regard to mitigation strategies (UNFCCC 2016).

As well as the negotiations described above to reduce greenhouse gas emissions, recent decades have seen many activities at local, national and international levels to help to adapt to climate change. Adaptation means taking action to reduce vulnerability to climate change, for example, through the development of river flood defences or heat and drought tolerant crop varieties. Recent research assessed by the IPCC (2014a) suggests that adaptation could half some of the risks to people from climate change, but adaptation options to protect the natural environment are much more limited.

Fossil fuel emissions from some countries, such as China, have risen dramatically in recent years, although preliminary analysis shows

Jens Ickler / Alamy

little or no increase in energy–related emissions of carbon dioxide in 2014 and 2015 (Olivier et al. 2015). Reductions in greenhouse gas emissions have been achieved in some developed countries that agreed to modest reduction targets under the Convention's Kyoto Protocol in 1997 (UNFCCC 2014b). Under the Kyoto Protocol, the UK committed to reduce its greenhouse gas emissions by 12.5 % below 1990 levels over the period 2008–2012. In 2012, UK emissions were 25 % below 1990 levels, so the UK exceeded its Kyoto target (DECC 2014). In 2008 the UK Government passed the Climate Change Act – the first country in the world to introduce such national legislation. Under the Act, the UK is committed to reduce its greenhouse gas emissions by 80 % (relative to 1990 levels) by 2050 and to meet a series of five year carbon budgets (Committee on Climate Change 2008). The Act also commits the Government to prepare the country for the risks from climate change. The UK's first Climate Change Risk Assessment was published in 2012 (Defra 2012) and a plan of how the UK will address these risks was published in 2013 (Defra 2013). The Risk Assessment was updated in 2017, identifying key risks for the UK including flooding and heatwaves (see Chapter 3).

2.5 Summary

Evidence of warming within the climate system since the mid–19th century is now more extensive and robust. The atmosphere and ocean have warmed, snow and ice have decreased, sea level has risen, and the concentrations of greenhouse gases have increased. Warming of the climate system is now considered "unequivocal" and many of the changes occurring in the climate system are unprecedented over decades to millennia.

There is now stronger evidence of a human influence on global climate and it is now 95 to 100 % certain that human influence has been the dominant cause of the observed warming since the mid–20th century. Continued emissions of greenhouse gases will cause further warming and changes in all components of the climate system – this conclusion has remained unchanged over successive IPCC reports.

If greenhouse gas emissions continue to rise at their current rate, climate models estimate that by the end of the 21st century global temperature could increase by between 2.5 and 5°C (relative to the period 1950–2005). Under a scenario where sustainable energy is adopted, warming is likely to range between 0.25 and 1.75°C.

The warmer the world becomes, the higher the chances of severe, pervasive, and irreversible impacts. Accordingly, over the last decade there has been more research on how to limit climate change. This will require substantial and sustained reductions of greenhouse gas emissions. Even significant reductions in global greenhouse gas emissions will not avoid the impacts of climate change completely, so measures to adapt to climate (to manage risks and increase resilience) are needed alongside mitigation.

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3. The future climate of the UK

Maskell, K

In the previous chapter, information about climate change on a global scale was presented. To understand what this means for UK gardening and horticulture, we need to look at how climate change might affect the UK.

3.1 Characteristics of UK climate

Before looking at how UK climate has changed in the past and how it might change in the future, it is useful to remind ourselves of the broad aspects of UK climate. The prevailing south westerly winds from the Atlantic Ocean exert a strong influence over the UK giving it a temperate, maritime climate with relatively mild, wet winters and warm, relatively wet summers on average. Within the UK, climate varies considerably at both a regional and local scale (Fig. 3.1). There is a strong east/west divide in rainfall, with higher amounts falling in the west, and a north/south divide in terms of temperature. Hilly and mountainous areas tend to be colder and wetter. Coastal regions are generally milder in winter and cooler in summer, compared with areas further inland.

The other key aspect of UK climate is its variability over time. Climate is defined not just by the mean conditions, but also by the amount of variability or scatter around the mean. We experience this variability as day to day changes in weather or in varying weather conditions from one summer to another. The UK is positioned on the eastern edge of the Atlantic Ocean in the track of mid–latitude storms, whilst also subject to continental influences of mainland Europe. While on average our prevailing winds come from the southwest, the UK can be affected by Arctic air from the north, sub–tropical air from the south and continental air from the east (Fig. 3.2). These different air masses and circulation patterns bring differing weather to the UK (Section 3.4 looks in more detail at the UK's variable weather and climate).

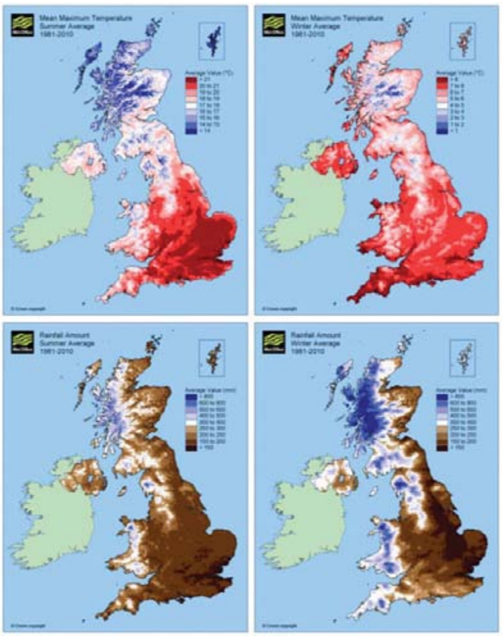


Figure 3.1: Clockwise from top left – average (mean) summer maximum air temperature (°C), average (mean) winter maximum air temperature (°C), and average winter rainfall (mm), average summer rainfall (mm). Averages refer to the period 1981–2010. Source: Met Office (2016).

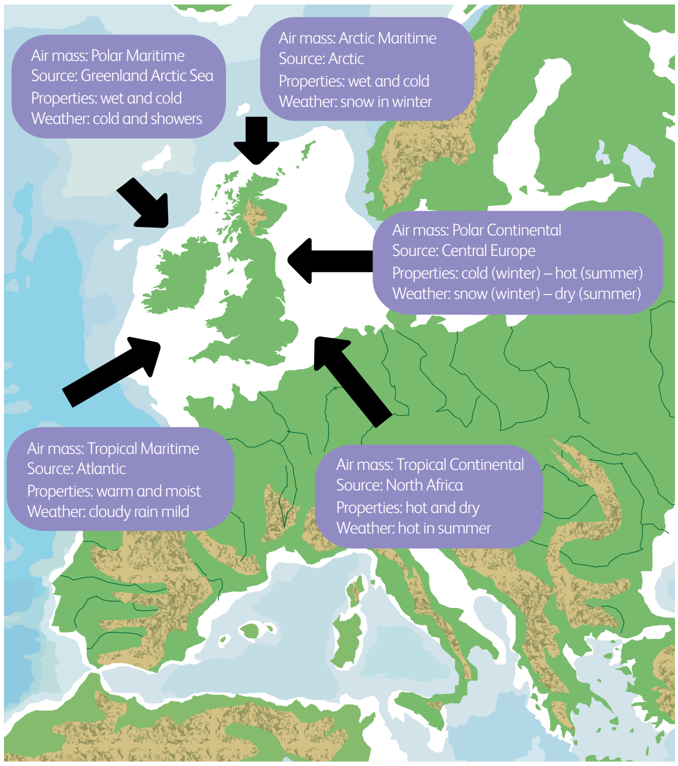


Figure 3.2: The air masses that can affect the UK and the weather conditions they bring.

3.2 How is UK climate changing?

3.2.1 Temperature

We are fortunate in the UK to have the longest instrumental temperature record in the world, the Central England Temperature (CET) record (Parker et al. 1992), with daily data stretching back to 1772 and monthly data back to 1659. The record is representative of a roughly triangular area enclosed by Lancashire, London and Bristol. It is clear from Fig. 3.3 that Central England Temperature varies considerably from year to year (by several degrees in some cases), but underlying that variability, there has been an overall trend towards warmer conditions, particularly since the 1960s. The increase in greenhouse gases from human activity is likely to have played a significant part in this warming trend (Karoly & Stott, 2006).

Trends in global mean and UK temperature are very similar to one–another, however, recent record–breaking global temperatures are not always experienced in the UK, primarily because the processes that drive year to year variation in the global climate are different to the UK.

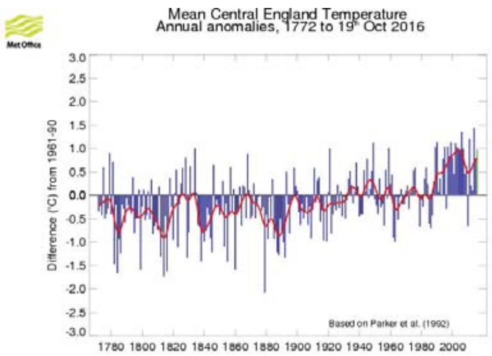


Figure 3.3: Annual mean Central England Temperature (CET) shown as a difference from the 1961 to 1990 average (blue bars). The red line highlights temperature changes on timescales of around a decade or longer. Source: Parker et al. (1992).

Nevertheless, 8 of the 10 warmest years for the UK have occurred since 2002, and the most recent decade (2006–2015) was 0.9°C warmer than 1961–1990. The natural variability of UK temperatures means that we would not expect to see progresive warming each year. For example, the cold year of 2010 is evident in the record (cold conditions prevailed in January and February and particularly in December 2010). We will look at cold winters later in Sections 3.4 and 3.5. Even in a warming world, natural variations will continue to cause some unusually cold seasons and years.

3.2.2 Rainfall

When we look at rainfall in winter (December, January, February) and summer (June, July, August) (Fig. 3.4), again the most striking aspect of the record is the variability from year to year and on decadal timescales (highlighted by the black line in each Figure). Note that Fig. 3.4 shows rainfall for England and Wales only, as this is the longest rainfall series available.

Over Scotland and upland areas of north England (not shown) there has been a significant increase in rainfall since the early 1900s (Fig. 3.4), with 7 of the 10 wettest years for the UK occuring since 1998. The winter of 2013/14 was the wettest in the entire record. We will return to the wet winter of 2013/14 in Sections 3.4 and 3.5 and also consider whether the increase in greenhouse gases is making such wet winters more likely. During summer, rainfall is highly variable from year to year (Fig. 3.4, bottom) and heavier summer downpours are expected in a changing climate (Kendon et al. 2014).

More generally, studies have shown an increase in precipitation over the 20th century when rainfall is averaged over all Northern Hemisphere mid–latitudes (within which the UK falls) (Hartmann et al. 2013). There is also evidence to suggest that the increase in precipiation is due in part to the observed human–induced increase in greenhouse gases (Zhang et al. 2007). Such an increase is consistent with a fundamental principal of physics: warmer air (due to increasing atmospheric temperatures) holds more moisture than colder air.

The character of rainfall may be changing over many parts of Europe (including the UK) with an increase in the number and intensity of heavy rainfall events (Hartmann et al. 2013). A recent report suggests that more days of heavy rainfall have been recorded in the UK over the most recent decade, in comparison with earlier decades for which data exist (Kendon et al. 2016). There is, however, a lack of information on rainfall changes at hourly timescales (e.g. sudden thunderstorms).

3.2.3 Frost

There are several different types of frost, with air and ground frost being the most commonly used in climate projections. Ground frost is when the surface temperature of the ground, trees or other objects falls below the freezing point of water. Although a type of ground frost, grass frost can occur when other surfaces do not freeze, and it is possible for this sort of frost to occur up until early summer. The Met Office ground frost metric can be interpreted as a grass frost measure, as it is recorded from a thermometer which is open to the sky, but suspended horizontally and lightly resting on the tip of short cropped blades of grass (personal communication, Dr Mark McCarthy, November 2016). Air frost occurs when air temperature falls below the freezing point of water and is typically measured 1 m above the ground surface (Met Office 2013c).

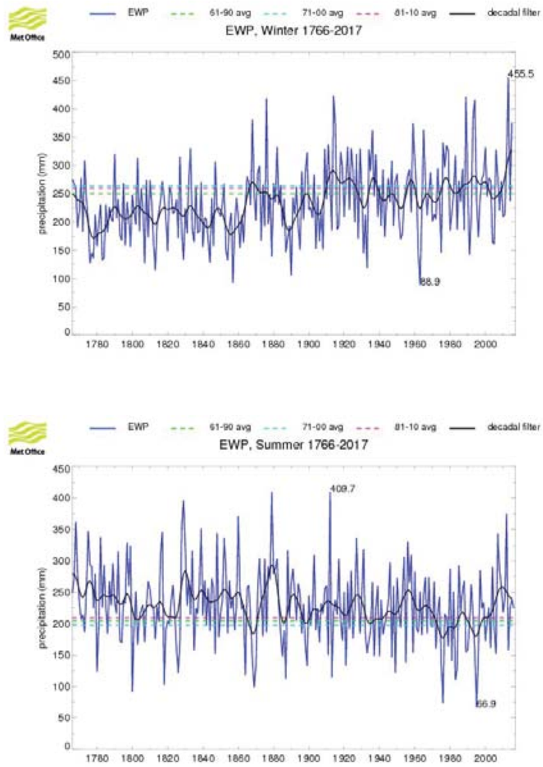


Figure 3.4: Precipitation (mm) in England and Wales during winter (December, January, February) (**Top**) and summer (June, July, August) (**Bottom**). The black line highlights decadal timescale variations from 1780 to 2017. The average England/Wales precipitation for 1961 to 1990, 1971 to 2000 and 1981 to 2010 is shown by the green, blue and pink dashed lines respectively (Met Office 2016b).

Figure 3.5 shows that a decrease in the number of air frost days has been observed across the entire country from the early 1960s to 2015. Ground frost can occur without an air frost on clear, still nights when air temperatures fall to 1 or 2 °C. Days of ground frost have been declining, although this tends to be due to a noticeable decrease during November and December, with days of ground frost in February and March remaining relatively unchanged to the 1961–1990 average (Fig. 3.6).

3.2.4 Sea–level rise

During the 20th century sea level around the UK coast rose by around 1.4 ± 0.2 mm per year (when also accounting for land movement), but the rate of increase since the 1990s has been higher than this (Fig. 3.7). Sea level is changing partly as a result of ocean expansion and melting land ice, and partly because of the movement of land in response to glacial melt at the end of the last ice age over 10,000 years ago. The latter is causing a general upward land movement in northern Britain and a downward movement in the south. It is estimated that over the 20th century the effect of land movement will have been quite small at Liverpool and Aberdeen, and about 1 mm per year in Newlyn, Cornwall. Extreme high sea levels (storm surges) are also of interest; changes in these are determined by changes in sea level and storminess in combination with tides. There is evidence that extreme high and low sea levels at Newlyn (since 1916) and Aberdeen (since 1946) have changed at roughly the same rate as the mean sea level (2.1 mm per year and 1.3 mm per year respectively) (Jenkins et al. 2008). The continuing rise in sea levels around the coasts of the UK is increasing the risk of tidal/coastal flooding.

3.2.5 Storms/windiness

UK winter weather can be mild and wet with strong winds or it can be cold and still. Such variability makes it difficult to detect trends in storminess. It is also clear from historical records that severe storms have always affected the UK (Burt 2007).

However, while there has been little change in the absolute number of strong storms, there is some evidence that the intensity of storms affecting the UK has increased since 1871 (Donat et al. 2011; Wang et al. 2013). For very strong storms, the mean intensity has increased significantly (Met Office 2014a), however, it is unclear whether these changes are the result of human–induced increases in greenhouse gases or whether they are the result of natural variations.

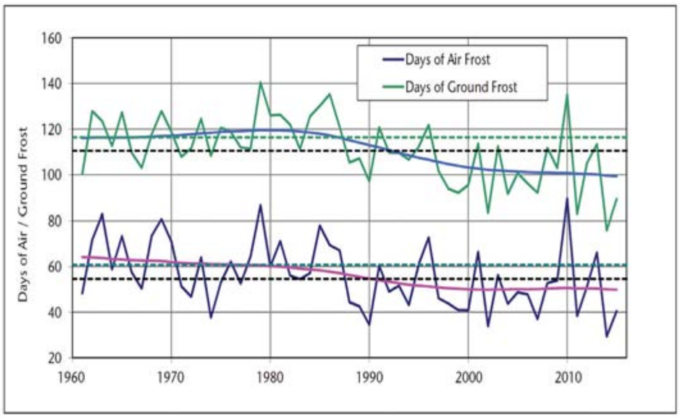


Figure 3.5: Annual number of days of air frost and ground frost for the UK, spanning from 1961 to 2015. The hatched black line represents the 1981 to 2010 annual average. Source: Kendon et al. 2016.

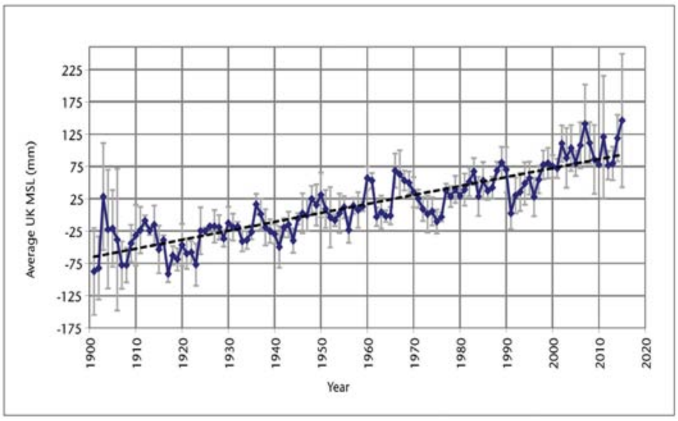


Figure 3.7: UK sea level rise since 1901 computed from sea level data from five stations (Aberdeen, North Shields, Sheerness, Newlyn and Liverpool). The black–hashed line indicates the linear trend of 1.4 mm per year. Error bars represent the uncertainty for each individual year (Kendon et al. 2016).

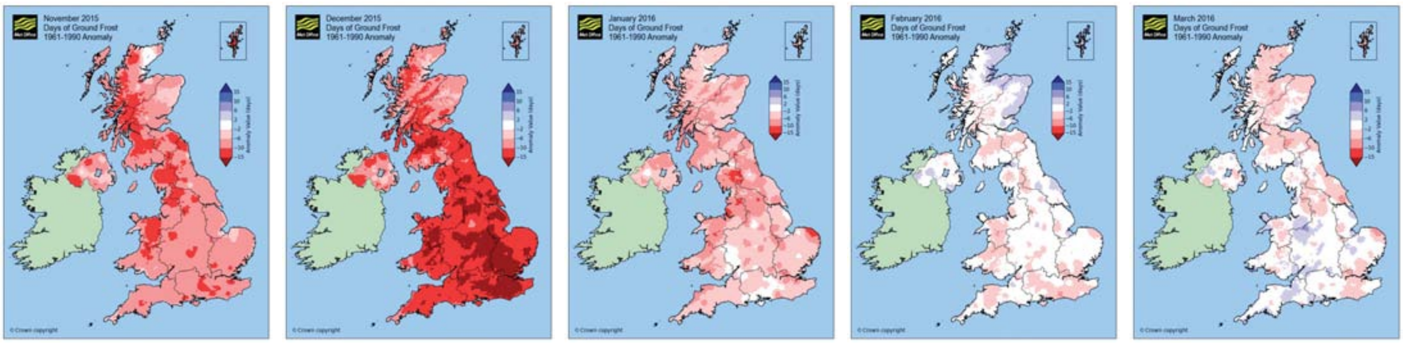


Figure 3.6: Days of ground frost observed through the months November 2015 to February 2016, relative to a 30–year averaging period (1961–1990). Source: (Met Office 2016c).

3.3 How will the climate of the UK change in the future?

This section will consider how UK climate might change in the future in response to increasing greenhouse gases. The 2002 report 'Gardening in the Global Greenhouse' ((Bisgrove and Hadley, 2002) was based on UK Climate Projections published in 2002 (UKCP02) (Hulme et al. 2002). Projections of future UK climate were updated in 2009 (UKCP09) (Jenkins et al. 2008), with the next update due in 2018. The results available in 2018 will be critical in helping decision–makers assess their potential risk to climate change.

Chapter 2 explained how global scale projections of future climate are produced. Assumptions are made about future greenhouse gas emissions (emission scenarios) and these are used as input to global climate models. The UKCP09 projections for the UK were made using a range of sophisticated statistical techniques to explore the potential range and probabilities associated with different levels of UK climate change at a spatial resolution of 25 km^2. Projections are based on three emission scenarios: high, medium and low. The output from many different variants of global climate models was used to try and sample a range of uncertainty (due to both natural variability and the incomplete understanding of the climate system). As a result, the UKCP09 projections are expressed in terms of probability. Typically we show the 10 %, 50 % and 90 % probability levels here, which are defined as follows (see Fig. 3.8 for an example):

10% probability of being below this level: i.e. very unlikely to be below this level

50% probability of being above/below this level: i.e. the central estimate (or median). The 50 % level does not equate to the most likely result, it simply shows that 50 % of the climate models results were above the projected value and 50 % below the projected value

90% probability of being below this level: i.e. very unlikely to be higher than this level

3.3.1 Changes in temperature and rainfall

Figures 3.8 and 3.9 show projected temperature and rainfall changes by the 2080s (for the medium emission scenario). Warming is projected to be greater in summer than in winter and in general, the UK is projected to become drier in the summer and wetter in the winter. There is a noticeable spread in the projections of summer rainfall: the central estimate suggests the UK will become drier, but there is a small chance that summers could become slightly wetter (see 90 % probability projections of summer rainfall). In other words, the projections suggest that the most likely outcome is that summers will become drier on average, but it is still physically plausible, although much less likely based on current evidence, that our summers could stay roughly the same or become wetter on average (Dr Mark McCarthy, personal communication, November 2017).

A summary of changes in temperature by 2080 under the medium emissions scenario:

1. Average temperatures are projected to increase in all seasons and all regions of the UK.
2. There is greater warming in summer than in winter
3. Levels of warming are largest in the south of the UK
4. By the 2080s winters could be 1˚C to 5˚C warmer, with summers 1˚C to 6.5˚C warmer.

A summary of changes in precipitation by 2080 under the medium emissions scenario:

1. In general, precipitation is projected to increase in winter and decrease in summer.
2. There is greater uncertainty in projections of precipitation than temperature
3. The change to drier summers and wetter winters is most marked in the southern half of the UK
4. An increased intensity of rainfall is projected to occur throughout the UK

3.3.2 Heat–waves, dry spells and frosts

As UK climate warms, we might see a very substantial increase in the occurrence of very hot days in summer (Fig. 3.10). For example, over the period 1961 to 1990 at Heathrow, there were typically 2 days a year when temperatures exceed 28˚C. By the 2080s (under a medium emission scenario) this could increase to an average of 32 days a year. The frequency of dry spells is also likely to increase across much of the country with more substantial increases in the south and east associated with lower summer rainfall (Fig. 3.10). Other large scale climate models have shown that an increase in drought throughout the 21st Century should be expected (Burke et al. 2010). The risk of air frost decreases by the 2080s for all four areas, especially in Dale Fort.

Climate models project an increase in the chance of intense precipitation and flooding (IPCC 2013). Although somewhat counter–intuitive given the increased likelihood of drought, precipitation is projected to be concentrated into more frequent and more intense events, with longer periods of dry conditions in between. The intensification of precipitation is of great

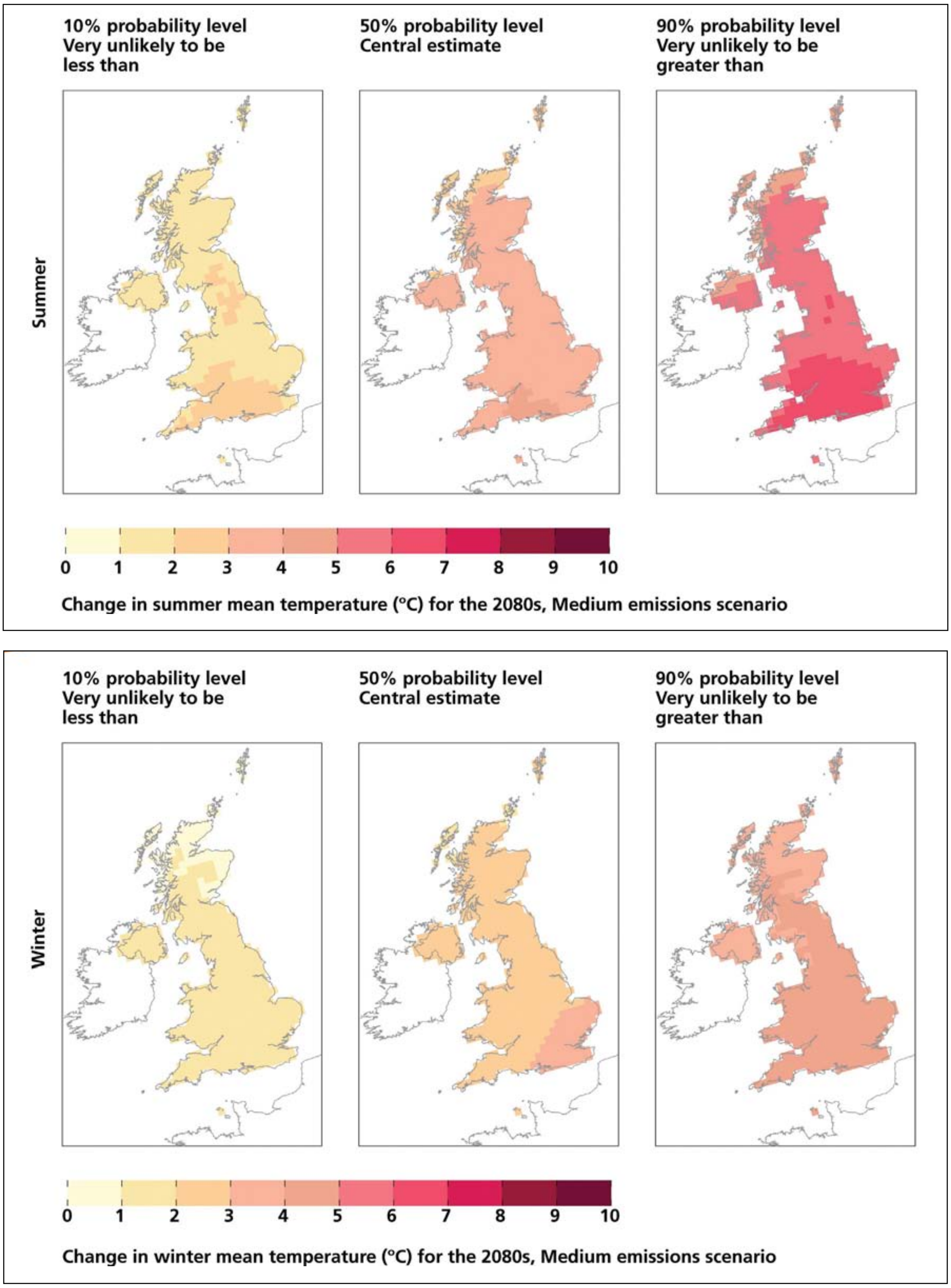


Figure 3.8: Projected changes in average temperature by the 2080s for summer (**Top**) and winter (**Bottom**) in °C for the medium emission scenario. Left, centre, right panels show: 10 % probability, 50 % probability and 90 % probability respectively. Predictions are relative to the 1961–1990 baseline. Source: Jenkins et al. 2009.

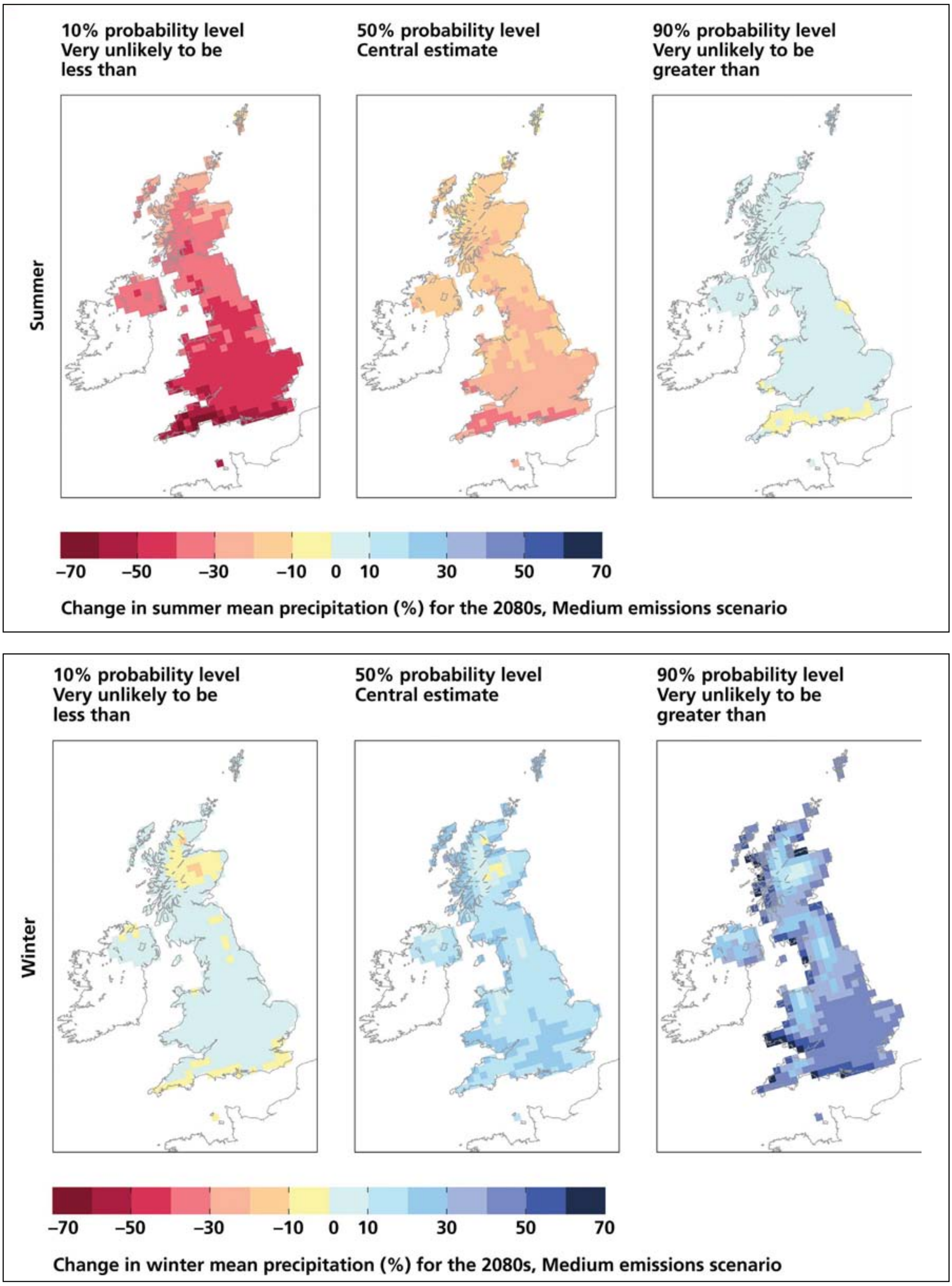


Figure 3.9: Projected changes in average precipitation by the 2080s for summer (**Top**) and winter (**Bottom**) in mm for the medium emission scenario. Left, centre, right panels show: 10% probability, 50% probability and 90% probability respectively. Predictions are relative to the 1961–1990 baseline. Source: Jenkins et al. 2009.

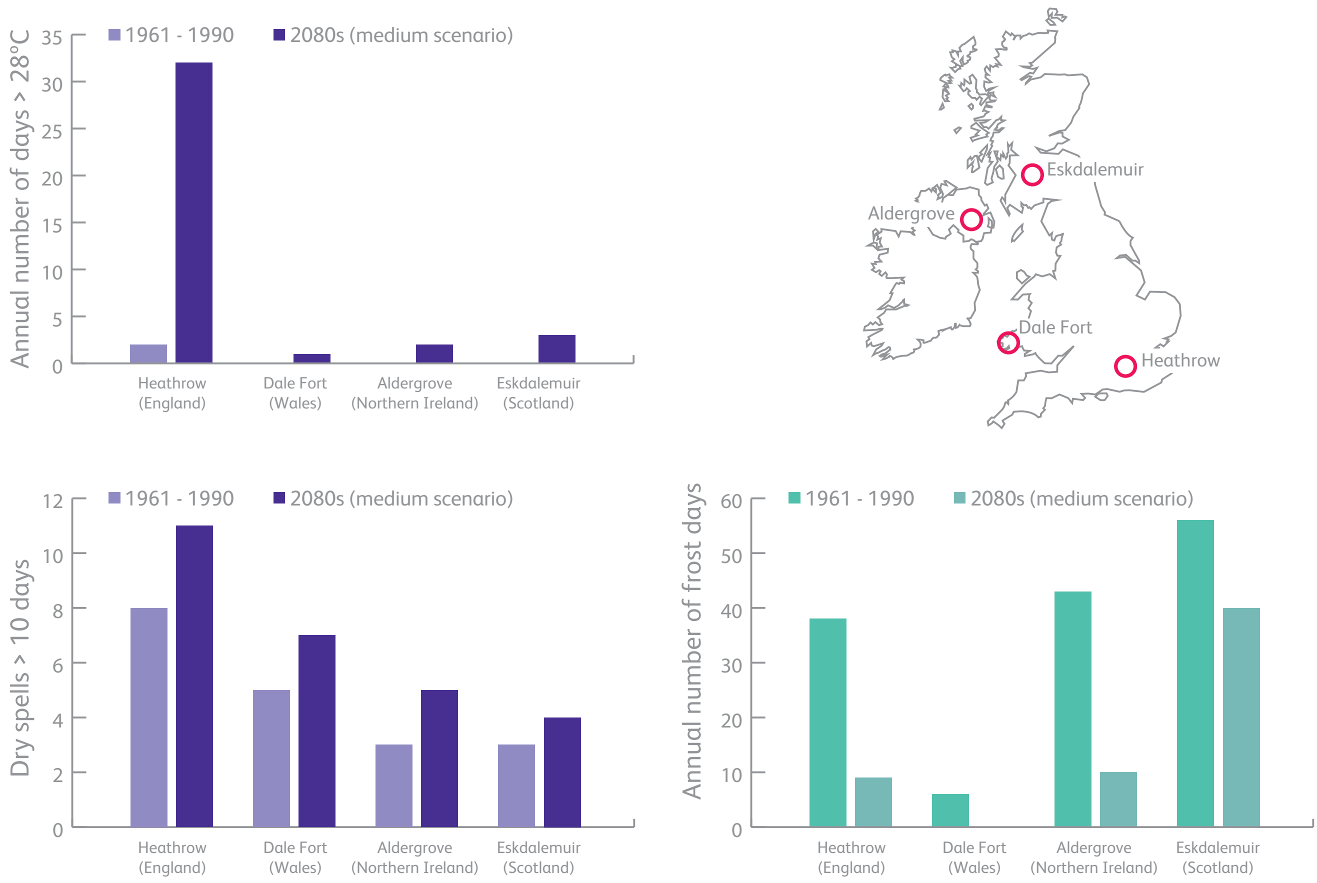


Figure 3.10: Clockwise from top left: annual number of days exceeding 28°C, map of locations of weather generator stations, annual number of days of air frost (days when minimum air temperature less than 0°C) and number of dry spells (defined as a single period longer than 10 days) over the course of a year. Results refer to the medium emissions scenario at the 50% probability level, based on 100 runs of the Weather Generator to a random sample of the projections. Raw data obtained from Jenkins et al. (2009).

importance to society due to the corresponding increased risk of flooding. Climate models at a very high resolution (1.5 km grid spacing) have shown that over the winter in the UK, hourly rainfall intensities will increase. The model also shows an intensification of short–duration rain during the summer, combined with a significant increase in the number of such events which are expected to be severe enough to cause serious flash flooding (Kendon et al. 2014).

3.3.3 Soil moisture

A supply of moisture from the soil is needed for plants to grow. Sufficient moisture is also needed at key stages of development for plants to flourish and for crops to reach optimum yields. Soil moisture is dependent on two key climate variables: rainfall and evapotranspiration[2]. In the UK, soil moisture deficits[3] tend to build up when evapotranspiration exceeds rainfall during summer, whereas the deficit is reduced in autumn and winter. Temperatures over the UK are very likely to increase during the 21st century, in all seasons, and summer precipitation may decrease. Both factors point towards drier soils in spring, summer and autumn. Soil moisture is also highly dependent on soil type, for example, sandy soils might be the most likely to experience a soil moisture deficit due to a relatively disaggregated structure relative to silts or loams.

For the baseline period of 1961 to 1990, the areas with the driest soils are located in the eastern and southern parts of the UK, notably Norfolk, Suffolk, Essex and Kent. These correspond to parts of the country where irrigation is most concentrated. In contrast, the least arid soils extend across much of Scotland, Wales, the southwest and northwest of England.

More areas will become arid by the 2030s, even under the low emissions scenario. These changes indicate a significant increase in the risks from dry soils and drought and an increased need for irrigation. By the 2030s, the irrigation needs of central England could be similar to that currently experienced in eastern England, and by the 2050s eastern, southern, and central England could experience irrigation needs greater than those currently experienced anywhere in the UK (Defra 2012)

[2] The sum of water loss from the earth's surface due to evaporation and transpiration. Evaporation: The change from liquid to gas. Liquid water evaporates from the surface of the earth to give atmospheric water vapour. Transpiration: The loss of water from the usually saturated air spaces within a leaf through open pores to the outside air. The open pores enable the exchange of gases for respiration and photosynthesis.

[3] The difference between the amount of water actually in the soil and the amount of water that the soil can hold.

3.3.4 Sea–level rise

As the world's oceans continue to warm and ice sheets and glaciers continue to melt, sea level rise is projected to accelerate. Local sea level rise depends on several other factors, including the movement of the Earth's crust. In the south of England land is subsiding at a rate of approximately 1 mm a year, so relative rates of sea level rise (i.e. a combination of absolute sea level changes and vertical land movements) are greater in the south than in the north of the UK. Central estimates suggest that relative sea levels around the UK could rise by approximately 20 to 50 cm by the end of the 21st century (relative to 1990) (Fig. 3.11).

Coastal areas are also at risk from an increase in the intensity and frequency of storm surge events (Church et al. 2013). Storm surges are the result of strong winds generating large waves, forcing a substantial volume of water towards the coast. Although extreme sea levels have been observed to occur with increasing frequency between 1901 and 2015 (Kendon et al. 2016), there remains uncertainty as to the geographical extent of a surge and the frequency at which they might occur (Archfield et al. 2016).

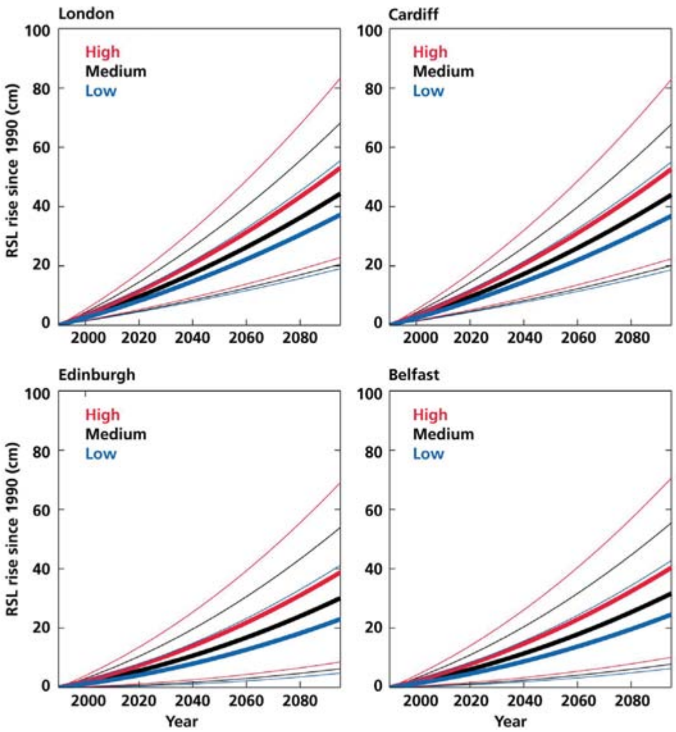


Figure 3.11: Projections of relative sea level rise (i.e. including local land movement) for high, medium and low emissions scenarios for London, Cardiff, Edinburgh and Belfast. Source: Lowe et al. (2009).

3.3.5 Changes in storminess

A recent analysis of storms over the UK suggests that by the 2080s there may be a slight increase in both the wind speed and the frequency of the most intense storms over the UK in winter. However, such projections are of low confidence because the simulation of the low pressure systems that can bring high winds and rain to the UK remains a challenge for global climate models (Zappa et al. 2013). Storminess over the UK also varies substantially from year to year and decade to decade as a result of natural variations.

3.3.6 Solar radiation and cloudiness

Summer solar radiation is projected to increase by a maximum of 8% by the 2050s under the medium emissions scenario. The largest increases are projected in the southwest of the UK (Fig. 3.12), whereas some decreases are observed across northwest Scotland. The overall effect of climate change is a net increase in solar radiation, however there will be substantial seasonal and regional variability (Burnett et al. 2014). These changes in solar radiation are linked to changes in cloud amount which is projected to decrease in summer (by 2 to 33%) with little change in the winter (± 10%) (Murphy et al. 2010).

RooM the Agency / Alamy

3.4 The UK's variable weather and its implications for projections of future climate

It was clear from Section 3.2 and 3.3 that a key aspect of UK climate is high variability on timescales of days to decades. For example, there might be a day with particularly heavy rainfall, or a year where the winter was particularly cold, or even a period of several years with cool summers. At the same time, the effects of human–induced climate change are becoming apparent – most obviously in the trend towards warmer UK temperatures.

3.4.1 The effect of year to year variability

The UK will continue to experience considerable variability over years and decades. So, while climate is projected to warm during the 21st century for all regions of the UK, cooler summers and colder winters will still occur, especially in the near to medium term. As the century progresses, cool summers and cold winters (as defined relative to today's climate) will become successively less frequent.

Figure 3.13 gives an illustration for Central England Temperature based on the results from ten different runs of the same regional climate model. All simulations show a similar level of warming by 2050, but the individual simulations show quite a different year to year progression. The simulation highlighted in blue shows an initial period when Central England Temperature decreases, but is followed by a period of rapid warming. Conversely, the simulation highlighted in red shows a period of rapid warming and a run of exceptionally warm years during the 2020s and 2030s. The results do not represent the full range of possible future outcomes, however, this example illustrates that climate projections are able to tell us about possible changes in the average climate, but they cannot predict all the weather that we will experience on the way (Dr Mark McCarthy, personal communication, November 2017).

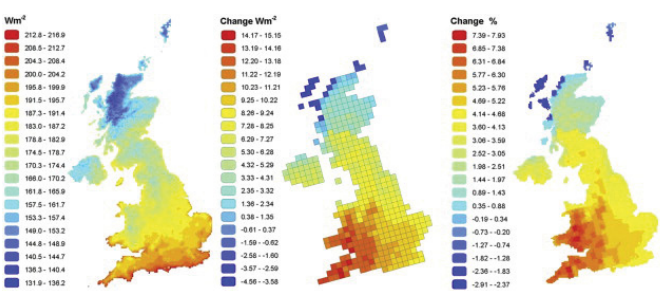


Figure 3.12: Summer solar resource: (left) baseline (1961–90); (middle) 2050s change in Watts per square meter (Wm^{-2}); and (right) percentage change from baseline. Source: Burnett et al.,

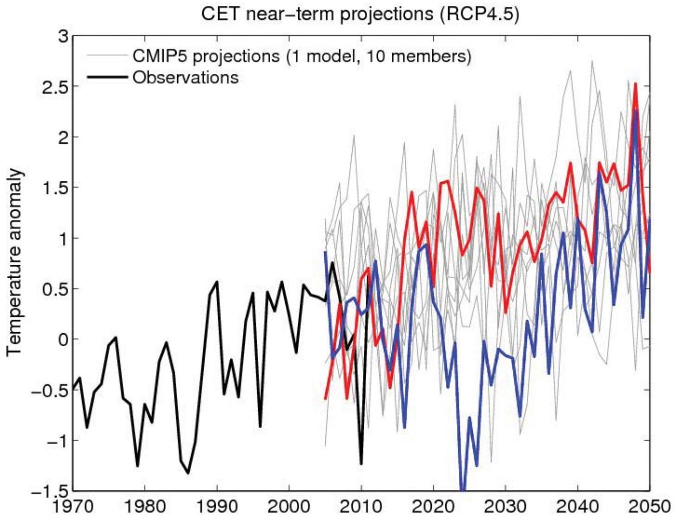


Figure 3.13: Central England Temperature from ten simulations of future climate (grey lines), with two simulations highlighted in red and blue. Source: Hawkins (2014).

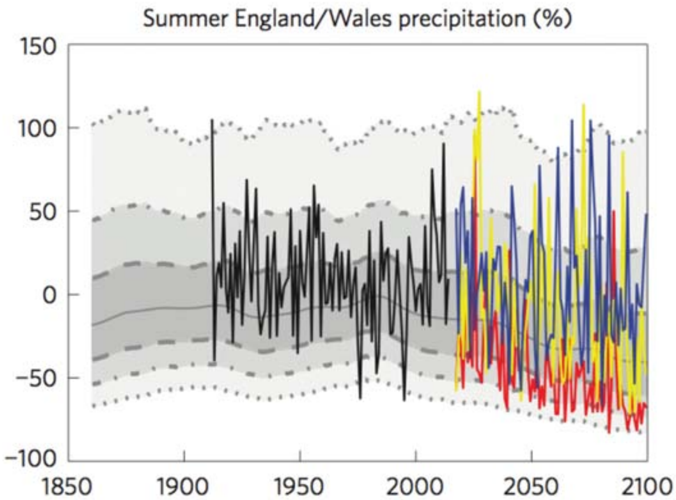


Figure 3.14 Projected percentage change in summer rainfall for England and Wales. Projections are based on future emissions under a high emissions scenario and are relative to the 1961–1990 baseline (see Chapter 2). Grey shading shows uncertainty, coloured lines are individual time series of year to year variation. Thick black line is observed winter values to 2015. Source: Sexton & Harris (2015).

Natural variability is even more pronounced for rainfall. For example, while summers on average may become drier, it will still be possible for wet summers to occur. The coloured lines in Fig. 3.14 depict independent runs of the same climate model, with some showing strong drying signals (red line), whereas others suggest that there will be the occurrence of a few very wet summers (blue line). Over the twentieth century, summers will most likely become drier, however, the chance of a 'very wet' summer only marginally reduces (Sexton et al. 2015).

3.4.2 The influence of the Gulf Stream

The Gulf Stream is part of a wider ocean circulation system known as the Atlantic overturning circulation[4] (Fig. 3.15). The circulation transports warm, surface water northwards and contributes to the temperate climate of the UK and the rest of western Europe. As the water travels north it cools and becomes denser. The cold, dense water sinks in the far North Atlantic and returns southwards in a deep ocean current.

Figure 3.15: A schematic of the Gulf Stream and the Atlantic overturning circulation. Warm water (red arrows) flows northwards and gives up its heat to the atmosphere. As the current moves further north it cools, sinks and then returns southwards at depth (blue arrows).

There are concerns that human induced warming may slow down the circulation (thought to be primarily due to glacial melt), weakening the Gulf Stream and exerting a regional cooling effect on the UK (Vellinga et al. 2002). Such changes in the circulation have occurred throughout the Earth's history. For example, it is thought that a large outburst of melt water entered the North Atlantic around 8,000 years ago which disrupted the Atlantic overturning circulation and caused it to shut down. The climatic impacts were widespread and included cooling over Western Europe (Masson–Delmotte et al. 2013).

Continuous direct observations of the Atlantic overturning circulation are only available since 2004. From 2004 to early 2012 there was a slowdown in the circulation of 10–15% (Robson et al. 2014) as well as considerable year to year variability. At present, it is not clear if this is part of a long term slow down or decadal timescale variability. Nevertheless, climate model projections suggest it is very likely that the Atlantic overturning circulation will decline in strength (by a few per cent to as much as 50%) over the 21st century, but it is very unlikely that it will undergo an abrupt transition or collapse over that timescale (Stocker et al. 2013). Such a decline in the circulation could lead to a relative cooling of the North Atlantic over the next few decades, although the warming effect of increasing greenhouse gases would likely override this. The projections presented in this chapter take account of this projected slow down and regional cooling effect.

3.4.3. The jet stream

The UK experiences predominantly westerly winds which, every few days, bring low pressure weather systems (also called depressions, or storms) that are associated with wet and windy weather. However, there are periods when these low pressure weather systems track to the north or south of the UK, and the UK landmass experiences high pressure and easterly winds of continental origin.

The track that storms take is influenced by a ribbon of strong winds in the upper atmosphere known as the jet stream. The jet stream exists at the boundary between polar and sub–tropical air (note: strictly the jet stream that influences UK weather is just one of the jet streams that exists in the Earth's atmosphere. In this report however, we will refer to it as "the jet steam"). The reason we are affected by successive low pressure weather systems is because of the boundary between sub–tropical and polar air, which creates a strong gradient from warm to cold and unstable conditions in the atmosphere. The storm systems mix warm and cold air and act to reduce the temperature gradient. The jet stream steers the course of mid–latitude storms across the Atlantic, but the storms also exert an influence on the jet stream. This is the dynamic and interactive nature of mid–latitude weather that makes UK weather hard to predict in detail beyond around five days.

In simplified terms, we can think of two different large–scale "states" of UK weather:

1. **STRONG JET.** Strong, westerly jet stream, storms regularly affecting the UK: weather unsettled, wet, cool and windy (especially in winter).
2. **WEAK JET.** Weak, meandering jet stream, storms take a path to the north or south of the UK: weather in summer dry and hot; weather in winter dry and cold.

Note that while these large–scale "jet stream states" exert a strong influence on UK weather, there are other factors that can affect the details of our weather that are not discussed here.

The influence of the jet stream on winter conditions

Figure 3.16 shows the "jet stream state" changing from winter to winter, but there is also distinct variability on multi–decadal timescales (i.e. a cycle of several decades where strong jet/weak jet winter conditions are more frequent). For example, during much of the 1980s and 1990s there were many winters with strong, westerly jet stream conditions and the UK experienced many wet and mild winters. In contrast, the 1950s and 1960s experienced more frequent winters with weak, meandering jet stream conditions and hence cold, snowy conditions.

[4] More strictly this is known as the Atlantic Meridional Overturning Circulation (AMOC).

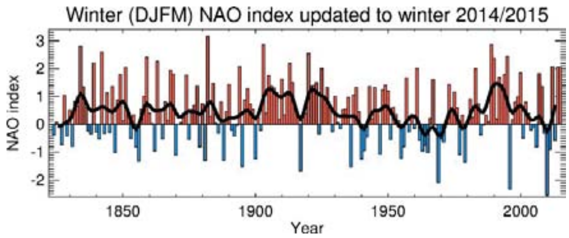


Figure 3.16: A measure of the "jet stream state" (NAO index) during winter (December, January, February, March) for each year from the 1830s to 2014/15. RED is equivalent to a STRONG JET/MILD UK WINTER state, while BLUE is equivalent to a WEAK JET/COLD WINTER state. Source: Osborn (2016).

The "jet stream state" can also help us to understand recent winter weather extremes. The winter of 2009/2010 was the coldest UK winter since 1978/79, with over 20 cm of snow in southern England in early January and over 30 cm in central and northern Scotland in late February. This winter can be clearly seen in Fig. 3.16 as the lowest value in the record (Met Office 2016e). The winters of 2013/14 and 2014/15 saw a return to a strong jet, mild/wet winter state. Winter 2013/14 was an exceptionally stormy season, with at least 12 major winter storms affecting the UK. The persistent heavy rainfall through the season made it the wettest winter in the long running England and Wales Precipitation series from 1766 (section 3.2.2). The winter of 2014/15 also had a "strong jet steam" index. Temperatures were near normal (as defined by the 1981–2000 mean), rainfall was near normal over much of the southern UK, however the northwest of England and western Scotland saw storms and higher than normal rainfall.

As the climate of the UK warms, we can expect this natural variability in UK winter weather to continue. When the jet steam is in a "weak/meandering state" in winter we can expect more frequent cold winters (although they may well be less cold than they would have been in the absence of human–induced climate change). So, in this phase, natural variations will to some extent "mask" the effects of climate change – particularly in the near term. Conversely, during decades when the winter jet steam is in a "strong/westerly state", these natural variations will effectively act to amplify the effects of climate change, although even in this phase there could still be a cold winter.

The influence of the jet stream on summer conditions

As suggested earlier in the report, UK summer rainfall is also highly variable from year to year and it exhibits multi–decadal variability (i.e. a cycle of several decades where wetter/drier summer conditions are more frequent). Recent research has linked this multi–decadal timescale variability in summer rainfall to a natural cycle in North Atlantic temperature. When the North Atlantic is in a "warm phase" there appears to be more frequent wet summers over the UK (Sutton et al. 2012).

The temperature of the North Atlantic is related to changes in ocean circulation, and it is thought that a southerly shift in the jet stream is associated with warm sea surface temperatures in the North Atlantic, bringing rain bearing systems over the UK (Knight et al. 2005; Sutton et al. 2012). There are some indications that the current warm phase in the North Atlantic could be coming to an end and this would coincide with a return to hotter, drier UK summers, however there is considerable uncertainty about how quickly this might happen (Robson et al. 2014).

3.5 Recent extreme weather events and seasons

Section 3.4 showed that the increase in greenhouse gases observed over the 20th century is already beginning to influence the weather and seasonal conditions over the UK. We have also seen that the UK is subject to large annual and decadal variability. The previous section explored some of processes that contribute to this natural variability. In Table 3.1, we look at recent extreme weather events and seasons, consider how natural factors and human induced climate change might have contributed, and discuss how such extreme events might change in the future.

3. The future climate of the UK

Table 3.1: a summary of recent extreme events. Adapted from Met Office (2014b).

Event	Characteristics	Recent trends/influence of natural and human–induced changes	Future occurrence
Drought of 1976	Most significant UK drought for at least the last 150 years in the UK, consisting of an 18–month period of below average rainfall starting in May 1975. Forest fires in Southern England destroyed trees; millions of pounds worth of crops were lost; widespread water rationing.	No trend observed in UK summer rainfall. 1976 drought occurred during period of more frequent dry UK summers, related to natural decadal variability in North Atlantic temperature.	Most projections suggest that droughts like 1976 are likely to become more common by 2100.
Hot summer 2003	Hottest summer for 500 years across parts of Europe. The UK experienced its highest daily maximum temperature on record (38.5°C at Brogdale in Kent on 10 August 2003). UK summer rainfall was 75% of the 1961–1990 average.	Human–induced climate change is already altering the likelihood of heatwaves. Events like 2003 previously had a probability of 1 in 1000 years, now estimated to be 1 in 100 years.	It has been estimated that, under a medium–high emissions scenario, more than half of summers in Europe could be warmer than 2003 by the 2040s.
Cold winter 2010/11	UK temperature in December 2010 was the coldest for at least 100 years. Temperatures regularly fell to between -10°C and -20°C overnight. Many places saw temperatures struggling to get above freezing by day.	Weak/meandering jet, polar air affecting UK, part of natural variation in jet stream position. Likelihood of occurrence of cold winters has decreased due to climate change: cold December temperatures like 2010 are about half as likely now as they were in the 1960s.	Early results suggest that cold winters like 2010/11 are still expected to occur, although with diminishing frequency, interspersed between warmer wetter winters, to the end of the century.
Wet summer 2012	Wettest UK summer since 1912. Many parts of UK had more than double their average rainfall. Widespread flooding.	Increased frequency of UK wet summers since 2007 have been linked to the warm phase of a natural cycle in North Atlantic temperature (although this is only one influencing factor).	Projections in general suggest drier summers for the UK, although some projections show a slight increase in summer rainfall. Significant year to year and decade to decade variability in UK summer conditions is still to be expected. In near term (decades) the natural cycle in North Atlantic temperature is likely to change to conditions favouring drier UK summers.
Spring 2013	Cold and snowy start to Spring. Second coldest March in the UK record since 1910.	March 2013 was associated with weak/meandering jet conditions and cold, easterly winds over the UK. Appeared cold because of recent warmer springs, but temperatures not unprecedented.	As the atmosphere warms the frequency of cool spring seasons is likely to decrease, but severe cold seasons will still occur occasionally in future, especially in the near–term.
Wet winter 2013/14	England and Wales rainfall highest in 248 year record. Strong winds and high tides caused coastal damage and flooding. Extensive river flooding.	Strong jet stream conditions across the Atlantic. Winters as wet as 2013/14 will be more likely. Intensity of UK rainfall has increased and this is physically consistent with human–induced warming of the atmosphere.	Projections strongly suggest wetter winters for the UK. Frequency of extremely wet years very likely to increase. Some years will see more rainfall than average, some less than average.

3.6 Summary and discussion

3.6.1 Current and near term (present to the 2040s)

The human–induced increase in atmospheric greenhouse gases is already affecting UK climate which has warmed by around 1°C since the 1950s. The likelihood of warmer than average conditions and warm extremes (e.g. summer heat waves) has already increased significantly in the UK. For example, it is estimated that over Europe as a whole, a 1 in 50 year heatwave (defined as being 1.6°C above the 1961–90 average) now has a probability closer to 1 in 5 years.

On a timescale of several decades, it is virtually certain that the warming trend will continue, thus further increasing the likelihood of warm extremes (Christidis et al. 2014). The highly variable nature of UK climate will continue and cooler than normal days, seasons and years will still occur.

Winter rainfall in England and Wales has increased slightly over the 20th century, although year to year (and month–to–month) variations are so large that this trend is not statistically significant. Over Scotland there has been a more significant increase in rainfall since the early 1900s. Heavy rainfall has probably increased in intensity and frequency in recent decades. Such a change is physically consistent with a warmer world, so it is likely that in the near term there will continue to be more frequent heavy rainfall events compared with past decades. The chance of a very wet winter is also expected to increase.

In summer there has been no long–term (century timescale) trend in rainfall over the UK. However, warmer temperatures mean that in summer there will be higher evaporation from the soil, thus increasing the risks of aridity. By the 2030s there is likely to be a significant expansion of more arid soil conditions over the Midlands and eastern and southern England.

As well as year to year variability, UK winter and summer conditions also exhibit natural cycles of several decades when wet/mild winters or drier summers are more common. For example, during the 1980s and 1990s wetter/mild winters and drier summers were more common. Some of this variability appears to be linked to natural cycles in the temperature of the North Atlantic. A change in North Atlantic temperature from the current warm phase to a cold phase is likely (although it is difficult to predict exactly when it will happen). Such a change would probably increase the occurrence of warm, dry UK summers, although this research is quite preliminary and the natural cycles in North Atlantic temperature are not the only factor that affects summer weather conditions over the UK. There is less information about how the natural decadal cycle of winter temperatures and rainfall might evolve in the coming decades.

3.6.2 Medium and longer term (2050 to 2100)

All areas of the UK are projected to warm, with the largest changes over the southern half of the UK. Such warming over the 21st century would significantly increase the chances of hot summers and heatwaves. The number of hot days (temperatures over 28°C) at Heathrow, for example, could increase to 32 days per year by the 2080s (range 10 to 67 days per year). A summer like 2003 could feel like a cool summer. Of course, our climate will be just as variable, so cold winters and cool summers could still occur.

Winters are projected to get wetter and summers to get drier on average and these changes are most marked in the southern half of the UK. A small number of projections suggest wetter summers or little change in rainfall, however, summers are much more likely to get drier than wetter. By the 2050s, winters could be up to 40% wetter (rising to 50% wetter by the 2080s). Summers in the 2050s could be 40% drier (50% drier by the 2080s). Heavy rainfall is projected to become more frequent and more intense. There is no consistent signal about how the wettest day in summer might change.

Wetter winters, rain falling in heavier bursts and rising sea level all point towards an increased risk of flooding. The Government's most recent Climate Change Risk Assessment (Defra 2017) highlights flooding from sea level rise, river flooding and surface water flooding as current and growing risks for the UK. Lower rainfall coupled with higher temperatures in summer will lead to significantly drier soils. Dry spells will become more common and irrigation needs will increase. By the 2050s for example, even under a low emission scenario, eastern, southern, and central England could experience irrigation needs above anything currently experienced anywhere in the UK.

3.6.3 What does this mean for gardening?

The remainder of the report focuses on what the projections outlined in Chapters 2 and 3 will mean for gardeners. Below is a short summary of the content that will be covered.

Key risks for gardening. flooding, waterlogging, soil erosion, wetter soils in winter, damage to plants from heavy rain, mild winters (changes in risks from pests, disease and lack of chilling), heat stress, drier soils, increased need for irrigation, unexpected/ occasional spring frost

Key opportunities for gardening. longer growing season, opportunity to plant a wider variety of species, reduced risk of spring frost, use of gardens/green infrastructure for cooling, how gardens and green spaces can reduce surface flood risk by heping to store "excess" water in winter that can be used to irrigate during the summer.

4. The survey

Culham A, Webster E and Bernardini C

4.1 Introduction

The 2002 report 'Gardening in a Global Greenhouse' included a brief survey on professional horticulturist's views on how climate change might affect the management of public gardens at the time. Most of the participants believed that, in the light of 1998 climate change models, the disadvantages would outnumber the advantages and the maintenance cost for heritage gardens would increase substantially. The survey offered guidance for future research and this prompted the decision to conduct an electronic survey of the public supplemented by interviews with professional horticulturists in order to assess both amateur and professional gardeners' perception of the potential impact of climate change on UK gardening.

An updated survey was conducted in 2013 and involved an online questionnaire of the UK gardening public. The survey received 1007 responses and covered a broad geographic area (Fig. 4.1) with respondents generally aged between 55 and 64 and educated to degree level or equivalent (Fig. 4.2). Gardening or horticulture was part of the lifestyle of 98 % of respondents and the majority visit public gardens at least once a month. Eighty–eight percent of respondents are members of a garden, heritage or a landscape association and overall, the survey is a broad representation of the gardening public.

Both groups were asked to give an account of their views on the implications of climate change on UK gardening practice. The results from both the survey and interviews were split into four themes: knowledge, concerns, experiences and willingness to adapt to climate change. The objective of this chapter is to compare the perceptions of the public and those of professional horticulturists under these four themes. The outcome of the study is a snapshot of how UK gardening is coping with a changing climate and it should be noted that the survey followed the second wettest year on record at that time.

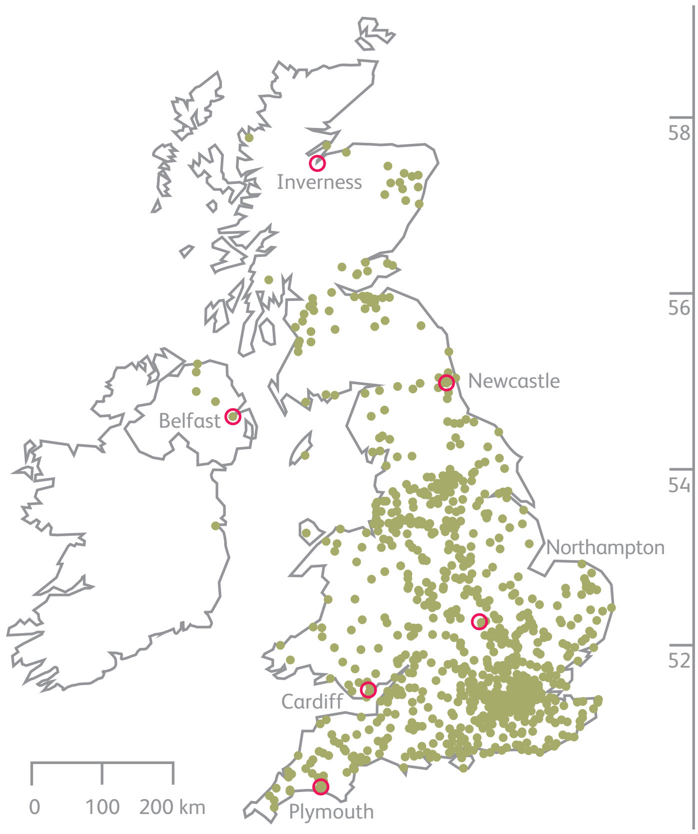


Figure 4.1: The distribution of survey respondents based on postcode.

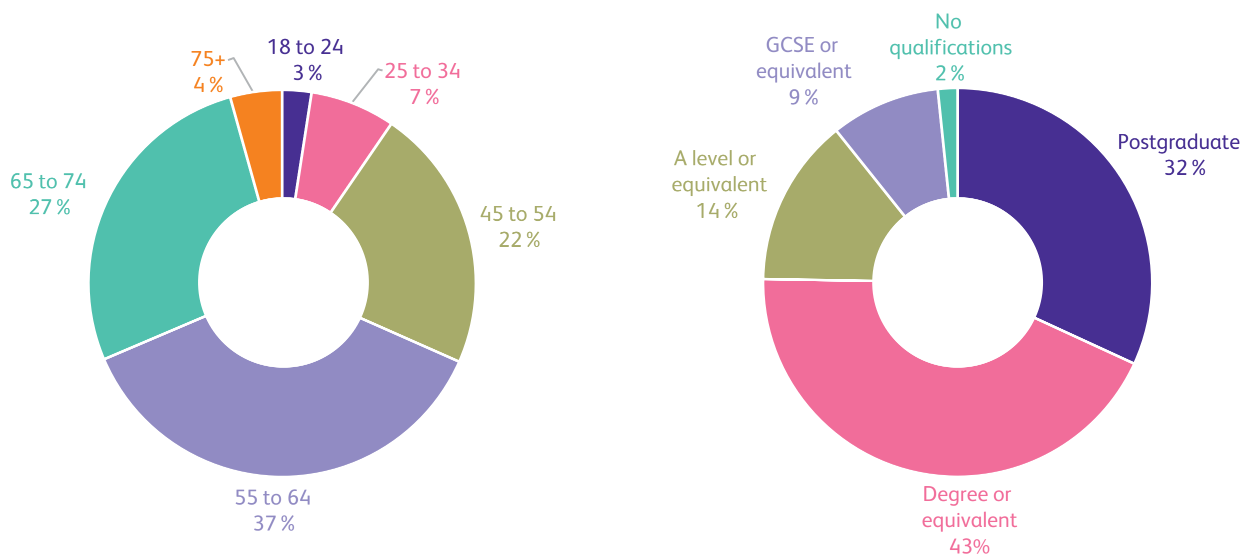


Figure 4.2: Age (**Left**) and level of education (**Right**) of survey respondents.

4.2 Knowledge: general beliefs and understanding of climate change

The majority of people that took part in the survey believe that climate change is happening and feel that both human and natural factors are contributing to this. The interview respondents had the opportunity to expand on their observations of climate change, which revealed the consensus that the UK has been experiencing a change in the incidence and severity of weather conditions over the last decade and many believe that weather extremes are linked to long term changes in global climate. In light of recent scientific evidence, this was indeed an astute observation. Climate models developed since the completion of the survey have indicated that human influence has very likely contributed to the observed changes in frequency and intensity of temperature extremes since the mid–20th century (Kendon et al. 2014). Additionally, a warmer atmosphere is able to retain more moisture, therefore the frequency and intensity of extreme rainfall events is likely to be coupled with long–term changes in global temperature.

Although there is a general belief that climate change is happening, only 2% of survey respondents feel that they are prepared for gardening in a changing climate. It was evident from the interviews that there is confusion between the way climate change is explained by scientists and the media and the way it is actually experienced in gardening. For example, the major change that many interviewees had noticed was the unpredictability of weather conditions which seemed to contradict the expectations of global warming predicted a decade ago: "There was the idea of a warmer climate and ten years on we have an appreciation that changeable is a better description than warmer, and perhaps less predictable" (Martin Emmett, Director, Binsted Nurseries and Walbarton Nurseries).

There is confusion between the way climate change is explained in the media and the actual experience of gardeners. Perhaps this is the reason why the majority of respondents believe that their current understanding of climate change will only 'moderately' prepare them for gardening in a changing climate and why 38% of people feel that they might need help. Despite this, the vast majority of people do not seek support from garden centres, nurseries, parks or gardens on how to cope with projected climate changes.

The communication disconnect between the public and professional horticulturists was also evident from the interviews. For example, interviewees acknowledged that the gardening public are likely to experience similar problems to those faced by larger parks and gardens: "Heligan is a working garden and people can see what's happening and they're ok with paths closed occasionally and work being done. They can see staff struggling … and they can see the issues we have and relate them to their allotments and back gardens" (Mike Friend, Head Gardener, The Lost Gardens of Heligan). However, it was suggested that the delivery of factual, accurate information that people can rely on is integral to support the gardening public in preparing for climate change: "We need to go back to the basics of gardening and horticulture and get them right. The right plant for the right place, in the right environment and that's the role of garden centres like us, to give really good advice. Because I don't think you will get that in a place that just carries plants in a trolleys and puts them out for sale" (Adam Wigglesworth, Aylett Nurseries).

4.3 Concerns: perceived sense of vulnerability and associated risks

There is a perceived sense of risk and vulnerability associated with climate change and future challenges. The survey indicates that the majority of participants are concerned about the general effects of climate change and whether they will still be able to grow their favourite plants. In particular, they are worried about the impact of climate change on future generations, but they also think that climate change will pose a serious threat to them or their way of life. Only 9% of respondents were concerned with the cost of adaptation being too high and gardeners appear to have a proactive attitude as the majority of people feel that change now will make a difference in the future.

It is reported with confidence that an increase in frequency and intensity of extreme weather events is occurring in the UK (Chapter 3). Therefore, participants from the survey are justifiably worried that weather extremes will make gardening more problematic. Specifically, the results of the survey indicated that if gardening becomes a challenge in the future, drought and waterlogging will be the most critical factor in determining plant survival (Fig. 4.3). This concern was reflected in the outcome of the interviews, where the observed interchanging of dry spells and heavy rainfall compromises the health and survival of many plants and renders the soil unworkable for several weeks to a year: "Our Southern Hemisphere collection, especially the South African border, in recent years has struggled because of high rainfall over winter, which has led to rotting of underground rhizomes, tubers and bulbs" (Nigel Brown, Curator Treborth Botanic Garden).

Although winter waterlogging is an important consideration for plant survival, extreme events over the summer may result in increased leaching of important soil nutrients as intense rainfall following periods of drought will remove nutrients important to plant growth and survival from the soil (Knapp et al. 2008). Leaching of nutrients may be exacerbated if intense rainfall events come shortly after fertiliser or pesticide application, and the release of these chemicals into surface water can result in the accumulation of excess nutrients in waterways.

According to the survey, the introduction of new pests and diseases was considered the most important factor for plant survival after drought and waterlogging. Interviewees commented that changes in temperatures and precipitation patterns seem to be connected to an increase in the occurrence of common pests and diseases in addition to the introduction of new species. In some cases, climate and weather conditions are likely to have worsened the impact of pathogens by weakening the plant's defences and ability to cope with changes (i.e. physiological stress): "We have seen more diseases in trees and shrubs. Although we cannot pinpoint climate change as a factor, generally the very poor growing conditions we experienced has exacerbated the effects of some of these incipient diseases." (Nigel Brown).

Several gardens have witnessed the arrival, survival and spread of new diseases which are coping in different ways: "The climate is making diseases more prevalent. We tend to stick with British grown stock, because it's used to this climate. If we keep buying plants from the local area, they've got a better chance to survive any pests and diseases, because if the nursery is only twelve miles down the road, anything airborne is going to be in this area anyway" (Corinne Price, Upper Gardens and Apprentice Manager Wrest Park). Sticking to locally grown stock could restrict the spread of pests and diseases by reducing plant movement. Further, plants will experience less shock if transported within a local climate zone and are, therefore, more likely to establish quickly and have a greater resistance to attack by pests and infection from diseases. However, it might be more beneficial to switch to non–susceptible species as many new pests and diseases attack not just garden plants, but also native species that are locally adapted. For example, box is increasingly susceptible to box blight and caterpillars, and replacing with an alternative such as delavay privet (*Ligustrum delavayanum*) can give the same appearance but without the need for intensive pest and disease management.

Despite the heavy rain events and floods experienced in recent years, water availability is still likely to be a problem in the future as rainfall becomes increasingly sporadic. If water availability does become an issue, it will probably affect the horticulture sector which will need to adapt gardening practices and management. "In Cambridge we are in the driest part of the country and it is going to become a much more extreme growing environment. I can see the range of plants traditionally cultivated shrinking. Plants are selected very carefully, which we think have a decent chance to survive and perform, without needing any additional water input. Winter rainfall is also key for us in refilling aquifers from which we draw water via a borehole" (Tim Upson, Cambridge University Botanic Garden, now Director of Horticulture at the RHS). "The fact that we need to be more careful with the way we use water may well lead us to use different plants that will tolerate dry conditions" (Paul Jackson, Head Gardener, Kenwood House & Estate). Certainly since the survey and interviews were completed, the intensity and frequency of rainfall events has increased throughout the UK, indicating that there will be a greater need to capture water during rainfall events for use during interim periods of drought.

It was evident from the survey that water availability is a consideration for many, as the majority of respondents reported always having a water butt. An increase in unusual rainfall events noticed by survey respondents may have led to an increase in people purchasing water butts over the five year period preceding the survey. Alternatively, an increase in the use of water butts could be the result of a more parsimonious approach to water usage, as reflected in the 40% of UK households that have a water meter, a figure which is reported to be increasing each year (Ofwat 2013). Further, an increased uptake of water butts could be in response to hosepipe bans that were, for some parts of the country, in place between 2010 and 2012 due to a prolonged period of below average rainfall (Met Office 2013a). An increased use of water butts will likely alleviate the pressure on UK reservoirs in the southeast of England especially, where stocks have been declining (Environment Agency 2016). In essence, these results demonstrate an interplay between gardeners noticing unusual rainfall events, a need to reduce water use as a cost saving exercise and past experience of prolonged hosepipe bans. Regardless of the incentive behind the increase in the use of water butts, it is encouraging that gardeners show greater awareness of the importance of economical water usage.

However, the implications of unusual rainfall events are not isolated to water storage. For example, it was apparent from the interviews that intense rainfall events have increased in frequency which is associated with additional costs for gardens such as the repair of damaged infrastructure, gutters, pipes and drains: "It is always difficult to say what is weather and what is on–going climate (change), but we have had to do things like install drainage into some paths and areas on the garden, because the site can't take the excessive rainfall, while having to have the capacity for visitors. The garden has been overwhelmed by the wet years we had recently and we had to seriously upgrade the infrastructure." (Rowan Blaik, Head Gardener Charles Darwin's Home).

In addition to rainfall, unusual temperatures were considered very important to plant survival by survey participants and the effects of which have been observed by professional horticulturists. For example, prolonged and unseasonal low winter temperatures have caused extensive plant losses in addition to unseasonably early warm spells leaving plants that emerge early in the season vulnerable to late frost events: "We have started to use more reliably hardy plants than we did before and to protect more sensitive plants, such as the tree ferns." (Tim Miles, Head of Gardens Cotswold Wildlife Park & Gardens). These observations are congruent with published climatic data, where 2014 was the warmest year on record for England since 1659 and 8 of 10 of the warmest years in the UK have occurred since 2002. In a garden environment, water availability, nutrient supply and frost exposure can be managed to some degree which will secure the survival of many species that, outside of the garden environment, would not be able to survive. Indeed, rising temperature is one of the more familiar elements of climate change and recent climate models have shown that temperatures will continue to rise over the coming decades. This may bring advantages to the gardener, such as an increase in the use of gardens as social spaces. Furthermore, research has shown that certain plant species can have a temperature buffering affect, allowing the gardener some degree of control over the microenvironment of their outside space. However, public gardens opting to maintain their existing character will be more limited in the use of plants to dampen the effect of increasing temperatures.

Less than 26 % of survey respondents felt that light levels were an important factor to plant survival if gardening becomes a challenge in the future. However, light levels are an important consideration as the availability of light for plant growth can be limited by cloud cover and increasing fluctuations in high and low pressure weather systems, resulting in light levels that fluctuate sporadically. In contrast to the survey respondents, interviewees felt that light level is an important consideration, especially in spring when reduced light levels can result in slower and poorer plant growth: “Last year we had bedding plants which love sun and we didn’t have enough light. So, they didn’t grow as they were meant to and ended up being very small. …it’s just one of those things we have to be careful about now” (Corinne Price). Indeed, light levels are important as some plants require full sun, therefore, the layout of the garden may have to be altered to accommodate this, such as the removal of shading. Incidentally, recently popular gardening styles such as gravel gardens will reflect light to a greater extent than soil or vegetation cover. Furthermore, gravel gardens tend to be planted less densely, therefore maximising the light that can be reflected.

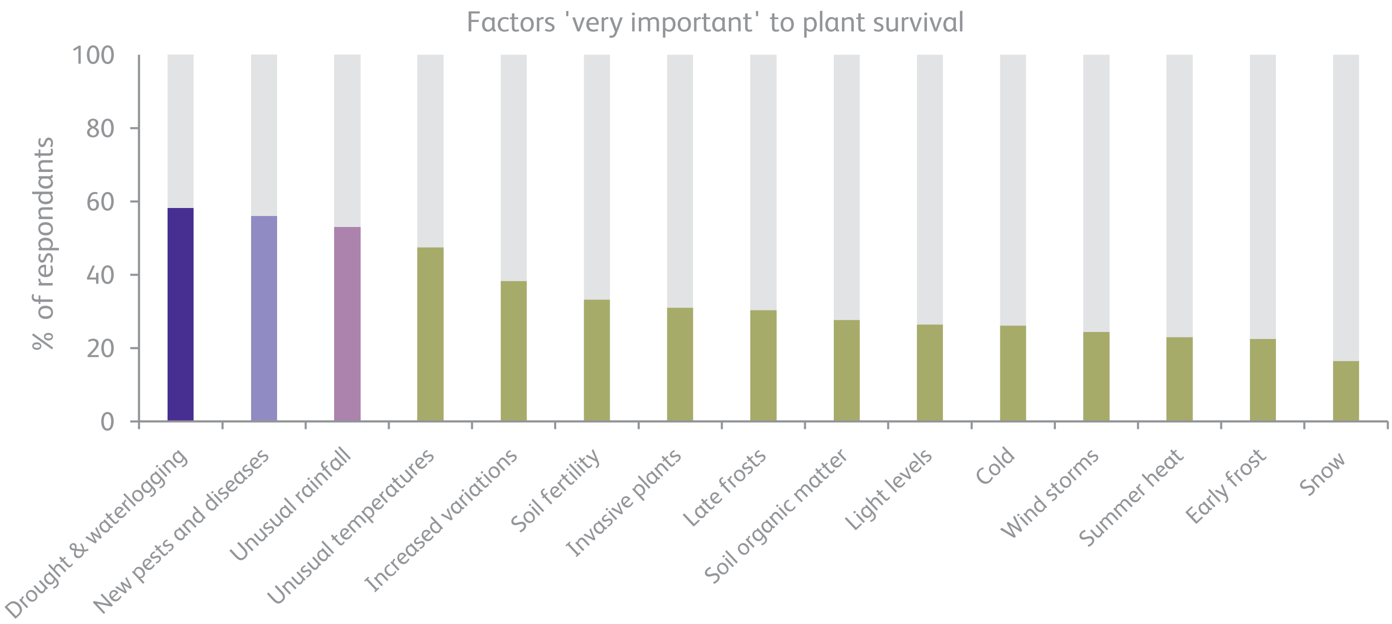


Figure 4.3: Factors considered to be the most important to plant survival if gardening becomes a challenge for the future according to the results from the survey.

Although a change in garden facilities and services, such as access restrictions, was a concern for survey respondents, a change in garden character as a result of climate change was found to be the biggest concern (Fig. 4.4). Therefore, it is likely that professional horticulturists will be inclined to maintain existing garden character, but this will probably be associated with an increase in running costs due to factors such as increased irrigation and maintenance of walkways. The results of the survey indicated that most people identified an increase in entrance costs to be most likely to affect public parks and gardens in the future (Fig. 4.5) and, for public parks and gardens, there will be a trade–off between the need to increase entrance costs to maintain character and compromising existing characteristics to minimise an inflation in ticket prices.

The majority of survey respondents think that there will be changes in public parks and gardens as a result of climate change, and the change in management of public gardens as a result of extreme weather events may clash with the expectations of visitors. For example, severe weather conditions such as storms, floods or heat, may necessitate extreme measures such as the closure of paths or parts of the garden and the sight of stressed plants might become more frequent. Such changes in the management of public parks and gardens was evident from the interviews: “We are increasingly having to restrict access during the winter, because of very wet ground conditions, which is potentially dangerous for the visitors and it can damage some of the native species in the lawn area.” (Nigel Brown).

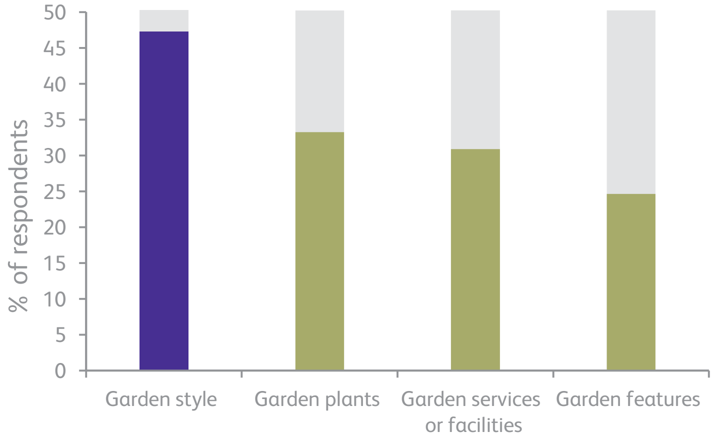


Figure 4.4: Aspects of public parks and gardens which survey respondents would not want to see change if drastic adaptations have to be made as a result of climate change.

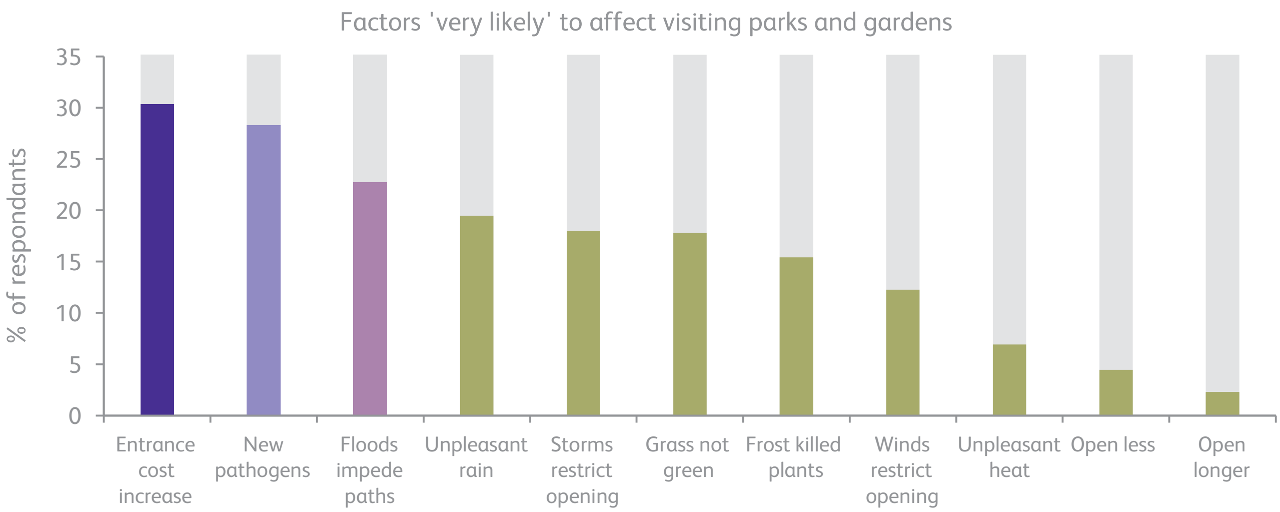


Figure 4.5: Factors considered to 'very likely' affect public parks and gardens in the future based on the results on the survey.

Climate change is often discussed in negative terms, especially associated with unpredictable and negative consequences on people's life and business. However, there are also potential opportunities associated with current and projected changes that might benefit horticulture. Survey respondents were aware of potential opportunities as the majority felt that climate will bring both opportunities and threats to UK gardening and the five most mentioned examples for each are presented in Fig. 4.6.

Opportunities	Threats
More and new varieties of plants and crops	Higher incidence of new and existing pests and diseases
Opportunity will rise from adaptation strategies	Loss of some native species and ancient woodlands
More flexibility in gardening practices	Increase in alien invasive species
Better chances of adaptation to UK changes for native species	Decrease of bees and other pollinating insects
Changes in gardening trend: wildlife friendly gardens will partially replace overly manicured gardens	More difficult growing conditions (also due to extreme weather events)

Figure 4.6: The five most mentioned opportunities and threats posed by climate change according to the results of the survey.

Although important, not all of the threats mentioned in the survey are as a direct result of climate change. For example, an increase in invasive species has historically been a product of the global transportation of plants, where species that appear to be climate restricted are in fact geographically restricted and thrive once introduced to a new environment. The invasion of non–native plant species is inevitably coupled with an increase in the incidence of new pests and diseases able to exploit the newly introduced species. Climate change may well favour invasive species as the UK climate becomes more akin to their native habitat. Furthermore, climate change could possibly facilitate the dispersal of invasive species by invoking physiological stress on native species.

A loss of native species could also be attributed to a decrease in biodiversity due to invasives, however, as discussed above, the link between an increase in invasive species and climate change remains unclear. Opportunities which arose from the survey were also recognised in the interviews. For example, the interviewees feel that gardeners are very resourceful and that with a positive attitude and the right adaptation strategy, most challenges can be turned into opportunities: "It's perception really. Threats and opportunities, it's actually all opportunities. It's a threat to the current species diversity we might have at this latitude, but with climate shift it just means that the species diversity that we have, will end up moving to more northerly latitudes" (Chris Wardle, Head Gardener Crathes Castle Gardens).

The planting of exotic species and changes in gardening trends are two opportunities identified in the survey (Fig. 4.6) which were also mentioned by the interviewees. Note that the term 'exotic' does not necessarily translate to species native to a warmer climate than the UK, rather exotic can refer to any species not native to the UK. However, this distinction was not clarified in the survey, and therefore for interpretive purposes, 'exotic' is assumed to be synonymous with 'tropical in appearance'. Some think that, with a shift toward a warmer climate, more exotic species are likely to succeed in domestic gardens, such as water hyacinth, and some conservatory or patio species might be able to be moved outside permanently. The industry is likely to benefit by offering a new range of garden plants that can grow well in a new climate. With some species benefitting from the changes, others will find the new environment challenging for their survival. However, shifts in plant distribution might change the character of UK gardens without necessarily resulting in an impoverishment of the UK landscape and plant diversity; "We are not losing plants due to weather changes, in actual fact it is probably more the other way, plants that you wouldn't think would be able to grow outside, are sometimes successful. We can push the boundaries; sometimes it's successful, sometimes not" (Mike Friend). Although this might be true for gardens located in the south of England, such as Heligan, opportunities to push boundaries with planting may be limited in other parts of the country. Moreover, there is little evidence as to how exotic species will respond to more frequent and intense climatic events.

Overall, the suggestion by the interviewees that a positive attitude can help with adaptation to climate change is important and, generally, climate change will present opportunities for the planting of new species and will result in changes in gardening trends throughout the country. There is a need for research to ensure that threats that may be exacerbated by a change in environmental condition, such as an increased risk of species invasion, do not outweigh possible opportunities.

4.4 Experience: the effects of climate change on gardening and adaptation

As a result of perceived climate change, approximately half of survey respondents have changed gardening practices and the majority have noticed changes in public gardens. This was mostly associated with the experience of those weather events that are causing permanent or recurrent changes in the garden and 79 % of people are paying more attention to the weather. The majority of survey respondents have noticed changes in their garden that could be related to climate change. For example, in the last five years, the vast majority have experienced plants dying as a result of waterlogging or frost. In this situation it is not a case of replacing like for like, instead plants which do not survive such conditions will have to be replaced with more tolerant species or cultivars. Alternatively, changes in garden management to allow better drainage, or planting in more sheltered areas, could allow the gardener to keep their best loved plants by giving them a better chance of survival.

Based on observed average temperature and precipitation maps, Northampton appears to be roughly located on the boundary between the warmer and drier south of England and the cooler and wetter north of England (Kendon et al. 2014). A change in the frequency in which survey respondents reported mowing their lawn was compared between respondents living north of Northampton to those living further south (Fig. 4.7). The results indicated that survey respondents living north of Northampton are mowing their lawns more often in early spring and late autumn in comparison to those respondents living further south. Southern areas will be more accustomed to higher temperatures and have perhaps been experiencing a slightly longer growing season than the north of England for several years. It is possible that in northern areas, the combination of increasing temperatures and precipitation is extending the growing season, whereas the extent to which the growing season can extend in southern regions is limited by increasing aridity.

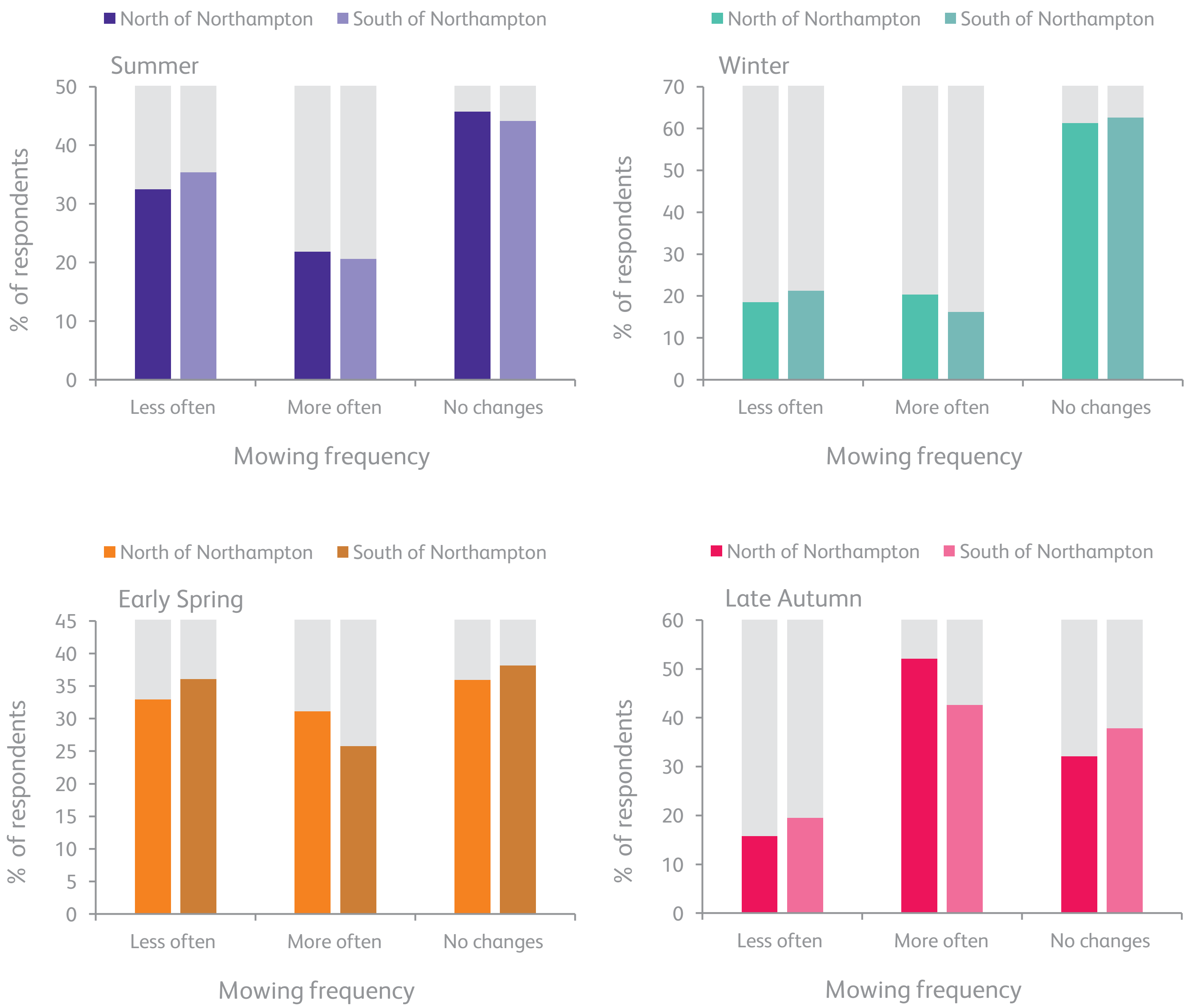


Figure 4.7 : Comparison of a change in mowing frequency reported by survey respondents above Northampton and below Northampton.

In the last ten years people have noticed changes in flowering events in private or public gardens with a similar number of respondents reporting both early and late flowering (Fig. 4.8). It was apparent from the interviews that an earlier flowering time will be the effect of rising temperatures for many plants, resulting in traditional dates for horticultural shows becoming out of synchrony with these flowering times: "This should be taken into account in long term planning. The range of bulbs that we show at Chelsea has diminished noticeably over the years, mostly for this reason. We now no longer show Narcissus there. No doubt the rose growers however are happy though" (Christopher Ireland–Jones, owner Avon Bulbs). In addition, some interviewees had noticed that changes in seasonal temperatures might have caused a shift in plant phenology for some species. The 'Kew 100' initiative shows how some specimens in Kew Botanic Gardens have responded to changes in the climate. For some of the species that have been monitored in the garden for several decades, phenology has shifted with the first flowering dates moving earlier in the year: "You can see clearly that since the 1980's plants have been coming into flowering earlier …and the UK Phenology Network looks at a wider span and there is no doubt at all that many species are flowering earlier. This has slightly changed since 2000 when winters have become less mild." (Sandra Bell, Wildlife and Environment Recording Coordinator, Kew).

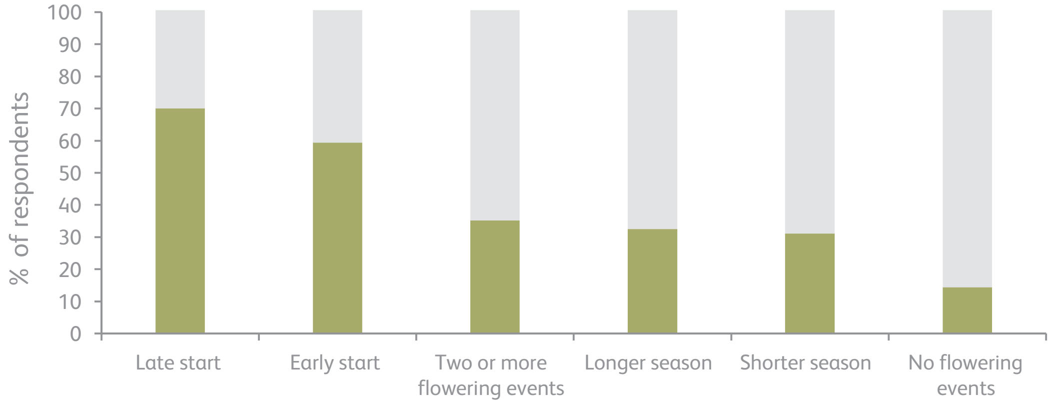


Figure 4.8: Perceived changes in plant phenology over the last ten years according to the result of the survey.

There is a shared perception that extreme weather events have intensified in frequency in the last decade, and coping with the erratic nature of weather has become the main problem associated with climate change. Survey respondents have experienced the effects of extreme weather events and this is also reflected in the interviews, where weather variability from year to year is making it difficult to predict what will do well and so planning ahead is becoming more challenging for gardens. For example, the change in weather patterns experienced over the last decade has meant that some gardeners have been left with a restricted choice of plant species, especially for annual bedding: "We have to be more choosy with plants and we are trying to use plants that are more tolerant to different conditions" (Chris Slatcher, Head Gardener, Wrest Park, English Heritage). The combination of climate change and pests and diseases is another reason gardeners will have to be selective in relation to bedding plants. For example, busy Lizzies (*Impatiens walleriana*) have become increasingly unavailable due to an outbreak of the impatiens downy mildew fungus (*Plasmopara obducens*) that arrived in the UK on commercial propagation material. *P. obducens* thrives in warm and damp conditions and a widespread outbreak occurred in 2008 following a particularly wet summer. However, outbreaks of *P. obducens* have been confined to *I. walleriana* (the common bedding busy Lizzie), with no cases reported for New Guinea *Imaptiens, Impatiens* x *hawkeri*. It is likely that projected climate change will leave northern parts of the UK most susceptible to further outbreaks of this disease and highlights a call for action to gardeners to consider more than just the survival of a plant, but rather the potential of the interaction of the plant species with climate change in facilitating the spread of pests and diseases.

4.5 Willingness: the effectiveness of adaptive behaviour

The majority of survey respondents are optimistic that they will adapt to climate change and are already changing plans and plants in their garden according to changes in climatic conditions. Although the majority would consider adapting the conditions of their garden to fit the plants they want, there is a sense of anticipation in relation to the opportunity to grow a wider variety of plants. However, it was clear from the survey that the willingness to adapt to climate change is based on the ability of plants to survive as the majority of people consider the growth requirements for a plant before purchasing. The 'general ability' of a plant to survive is more important than specific factors such as hardiness to frost or water consumption (Fig. 4.9). It was evident from the interviews that the horticultural industry are already aware of this, therefore with the climate projected to become increasingly erratic and extreme, there is a need to re–evaluate what the average gardener can grow. In the interim, it is recommended that nurseries should offer specialist advice on how to adapt gardens to climate change to help assist the gardening public in making informed plant choices.

The decision whether to buy an exotic plant is based primarily on its likelihood of survival in the garden and, although the majority of respondents would be willing to replace their favourite plant species with more suitable ones, only 13% of people found the idea of planting more exotics as a result of climate change appealing. In addition, the majority of people are more careful in protecting their existing plants, indicating a reluctance to observe a shift from the familiar character of the domestic garden. The apparent reluctance may be related to a lack of confidence amongst the survey respondents' knowledge of climate change (section 4.2).

For instance, the interviews highlighted that the advantage of public gardens is that trained and experienced staff are able to react to the unpredictability of the weather and domestic gardeners do not benefit from the confidence that trained horticulturists have. "Gardening in this climate means you have to know your plants better, you have to recognise if something needs to be done earlier, you can't just go by the book. So, for a domestic gardener that might be a problem because they wouldn't have that guidance, that in–depth, additional knowledge" (Chris Slatcher).

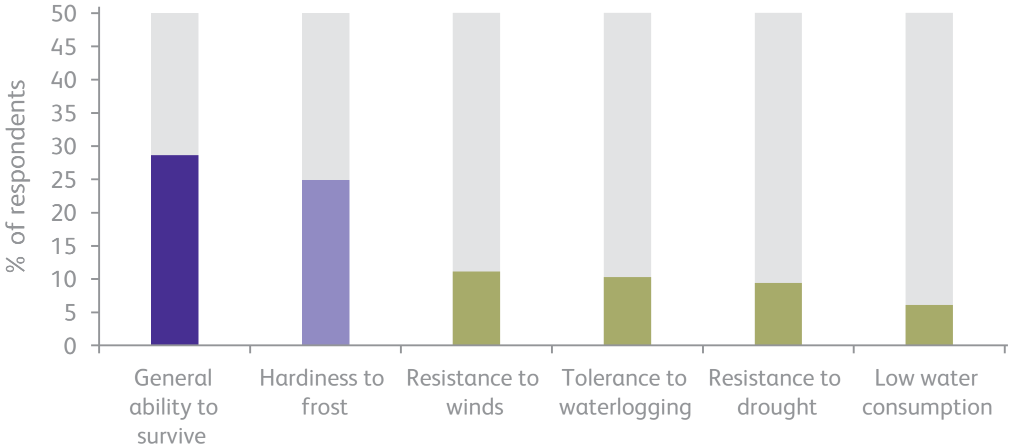


Figure 4.9: Most important prerequisite when buying outdoor plants according to the survey.

The results of the survey revealed that there is a conflict between the willingness of the gardening public to adapt to climate change in their own garden, and their willingness to accept change in public parks and gardens. It has been shown that there is a general sense that the gardener is willing to adapt their garden to the effects of climate change, such as changing plant choice. However, in relation to public parks and gardens, the majority of survey respondents would not want to see a change of character as a result of climate change (section 4.3). For example, when asked about their own lawn, the majority of respondents would not keep their lawn green over the summer and would be willing to accept a browner lawn. In public gardens, 20% of respondents would not be willing to accept a brown lawn, yet the vast majority of people would least like to see Astroturf replace lawn areas as a water efficient way to keep areas green (Fig. 4.10).

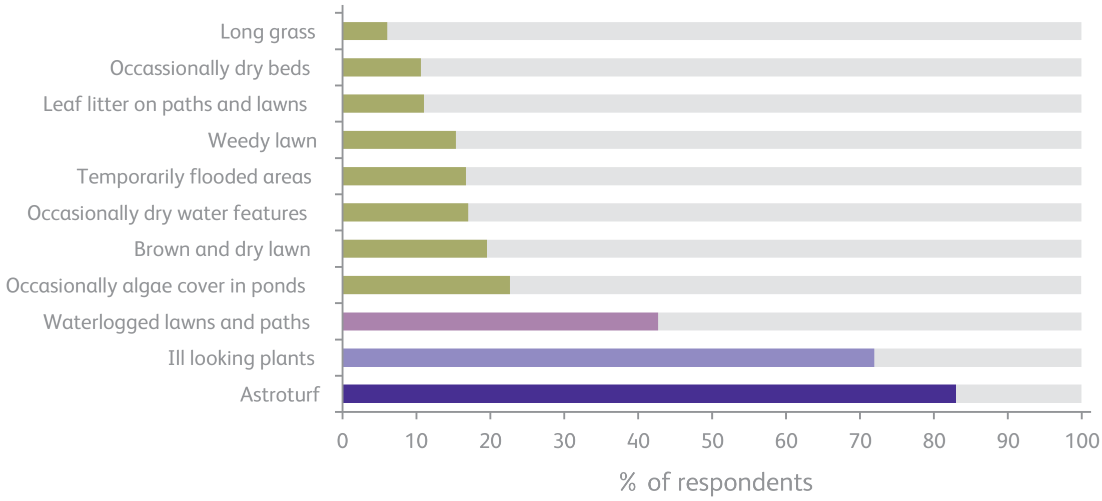


Figure 4.10: Conditions which respondents of the survey would be most disappointed to see in public parks and gardens

4. The survey

Despite an apparent lack of willingness of survey respondents to accept change in public parks and gardens, the results from the interviews indicate that it is likely that the character of public parks and gardens will alter as a result of climate change. For instance, some historic gardens and properties are finding it challenging to introduce efficient adaptation strategies because the problems of climate change are still not sufficiently understood and properly addressed in formal gardening. Maintaining historic accuracy of gardens will be made very difficult by changes in climate and will generate a conflict between historic conservation and adaptation. Some gardens are already facing this horticultural dilemma "In some years it is rare that suitable weather conditions coincide with the season so more skill and judgement is needed from site staff in timing many operations, and conventional management plans are losing their relevance and becoming increasingly expensive to carry out." (Jane Cordingley, Eltham Place Head Gardener).

The survey indicated that one in five respondents would no longer visit and a quarter would cancel their membership to their chosen society if garden character altered as a result of climate change, and this is likely to have financial implications for public parks and gardens. Further research is needed to determine what activities former members and visitors would choose instead. This information would inform a marketing strategy for public parks and gardens as it may be necessary to offer additional services if garden character cannot be maintained. Alternatively, visitor and membership attrition may be reduced if communication between professional and domestic gardeners was improved. For example: "We find the best thing is when we communicate with the public…. that the grass might be brown but it will come back. We are not wasting key resources to try and water 50–60 acres of grass" (Corinne Price). "We try and water more sustainably, and also to give this message to the public. We are growing plants that should perform reasonably well under drought conditions and our selection of perennial plantings seems to achieve that" (Tim Upson).

A shift to a milder climate may be beneficial for historic parks and gardens. Often historic gardens are based on formal Italian gardens and in the past, authentic species were swapped for alternatives better suited to the comparatively more temperate climate of the UK. Climate change could result in improved authenticity as more plant species used in formal Italian gardens can now be grown in the UK. Overall, climate change presents opportunities to the horticultural trade, such as increased sales opportunity as gardeners adapt their plant choice to species more tolerant of changing conditions. Similarly, there is an opportunity to increase sales of garden infrastructure, such as rain coverings, water storage systems or outdoor cooling systems as well as furniture for outdoor entertaining during the projected warmer summers. A positive attitude from horticultural professionals was a common theme in the interviews and will be important in finding creative methods for adaptation, such as maintaining historical character by replacing current plant species with an aesthetically similar species.

The horticultural industry and domestic gardeners should be reassured by an increase in the complexity of climate models in recent years that has resulted in an increase in the confidence of climate projections, both in terms of regional and seasonal trends and extremes. Climate models provide a means for gardening professionals to be prepared for future changes, whereas there is limited advanced warning of other potential threats to the horticultural industry, such as the outbreak of pests and diseases. For example, the character of historical gardens has recently been compromised by the expansion of the Box blight (*Cylindrocladium buxicola* (syn. *Calonectria pseudonaviculata*) and *Pseudonectria buxi*), and the resilience of the industry is evident in the adoption of management strategies to isolate infected areas or the use of alternatives such as *Ilex crenata*.

4.6 Summary of key findings

The results of the survey and the interviews confirmed that the vast majority of both the gardening public and professional horticulturists believe that climate change is happening, and both groups have noticed an increase in extreme weather events that is in line with the meteorological evidence of climate change presented in Chapters 2 and 3.

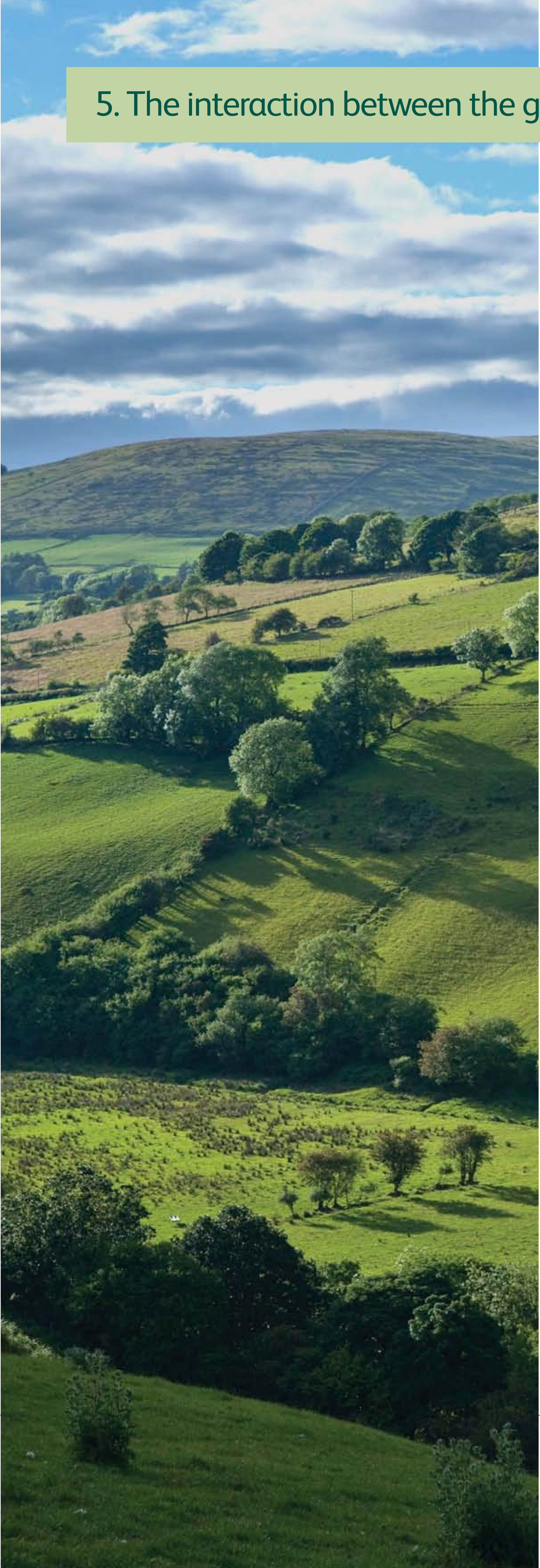
Gardeners are most concerned about the increase in incidence of drought and waterlogging as a result of climate change and the establisment of new pests and diseases which is further discussed in Chapter 5.

Survey respondents in the north of England reported an increase in the frequency of lawn mowing in spring and autumn which indicates an extension of the growing season. Most respondents had noticed a change in the timing of flowering events, although the number of people noticing earlier events was similar to the number noticing late events. This indicates that plants have begun to adapt in different ways to climate change and this is further discussed in Chapter 6.

A change in garden style and an increase in entrance costs to public parks and gardens as a result of climate change were concerns raised by the gardening public. Interviews indicated that professional horticulturists will be challenged in the future to maintain the character of historic parks and gardens and under such circumstances. Survey respondents would be less inclined to visit and membership numbers would decline if gardens changed. This chapter has also highlighted a lack of communication between professional horticulturists and domestic gardeners in relation to adaptation in garden management. Communication can be improved by delivering climate change information in an applied and practical way, where science and policy makers work to deliver key action points achievable by both domestic and professional gardeners.

Overall, climate change will present many opportunities to both domestic and professional gardeners, such as the increased use of the garden as a social space, but also with regard to innovation in plant choice. How management practice is likely to evolve as a result of climate change is discussed in Chapter 7.

5. The interaction between the garden and the natural environment



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Webster E, Culham A

5.1 Introduction

Garden management impacts on the natural environment, and changes to the natural environment will influence garden management in turn. The inherent interactivity of these two environments, managed and unmanaged, is a key element in the control of urban and rural human environments. In this chapter we explore these interactions, both positive and negative, and discuss what gardeners can do to ensure their contribution is as positive as possible.

The aim of this chapter is to describe some of the ways in which the garden interacts with the natural environment with a specific focus on how these interactions might evolve as a result of climate change. The importance of the interaction between the garden and the natural environment in maintaining biodiversity will also be highlighted.

The natural environment is a complex of the biological and physical environments; the interactions of plants and animals, landscape, weather and climate (Defra 2012). In the UK, almost all environments are managed to some extent and the term 'natural environment' relates more to the position on a spectrum of management intensity, and almost nothing is truly wild. Humans depend on functions carried out by the natural environment, which are collectively known as ecosystem services. Ecosystem services provide benefits to society such as climate regulation, but also food production through soil health. Impacts on the natural environment have consequences for the delivery of such services (UK National Ecosystem Assessment 2011).

Until recently, changing land–use and management has been the primary driver of change in the natural environment however, climate is likely to play a greater role in the future. For example, the UK is already vulnerable to extreme weather including severe winters, heatwaves, flooding and gales (Met Office 2014) and such events impose an additional stress to those ecosystems already threatened by land–use change (Defra 2012). The impacts of climate change on the natural environment are heavily researched and, in their most recent report, the IPCC concluded that:

'In recent decades, changes in climate have caused impacts on natural and human systems on all continents and across the oceans. Evidence of climate–change impacts is strongest and most comprehensive for natural systems.... Many terrestrial, freshwater, and marine species have shifted their geographic ranges, seasonal activities, migration patterns, abundances, and species interactions in response to ongoing climate change (high confidence).' (IPCC 2014b)

There is an expected general trend for poleward range shifts in wild species as temperature increases due to climate change (Parmesan et al. 2015) and gardens are important because they provide migration corridors for local species. In new areas that become available to plants as a result of climate change, competition between species will influence range shifts. Those that are unable to shift their distribution in line with climate change will likely experience local extinction due to encroachment by other species that are able to adjust their range (Morecroft et al. 2015). It is probable that southern UK species will gain suitable environment whilst northern UK species will lose out. To predict these changes in distribution, a process called niche modelling has been developed. This technique is used for understanding how species distribution is correlated with the climate, whilst also helping to inform land–management by highlighting key areas that should be managed to facilitate the migration of species to a more suitable environment as climate changes.

The second interaction between the garden and natural environment involves the possible expansion of invasive species. Gardeners plant both native and non–native species, with the latter being those that occur beyond their natural range due to deliberate or inadvertent introduction by humans or animals. Many non–native species do not present a problem at present, but some can spread and outcompete native species, resulting in environmental and economic damage. Non–native species are considered invasive when they are perceived as agents of change and pose a threat to human health, the economy or native biodiversity (Hulme et al. 2009). Throughout human history, the introduction of non–native species has been consistent with the growth of international trade. More recently, climate change has favoured some of these non–native species, increasing the risk that they become invasive (Hulme 2014). A large proportion of invasive plants come from horticulture because this is the industry involved with the greatest diversity of non–native species and particularly the cultivation of plants outside their ideal native climate. Climate change is likely to facilitate the expansion of non–natives and gardeners must be particularly aware of how their garden management practice might aid the introduction of non–native species to the wild. The Wildlife and Countryside Act (1981) recognised the need for legislation to control invasives through the inception of Schedule 9 that lists species for which it is a criminal offence to plant or cause to grow in the natural environment. Some are also prohibited from sale. Only a small minority of those listed on Schedule 9 were introduced by means other than horticulture such as dead man's fingers (*Codium fragile*); a seaweed transported to the UK by shipping.

Thirdly, the garden and natural environments interact through the transfer of pests and diseases. As with non–native plant species, this is facilitated by the international trade of plants by humans. The introduction of non–native plant species inevitably attracts pests and diseases adapted to exploit this new resource, and climate change may both increase the incidence and facilitate the spread of these (Parmesan et al. 2015). It is also important to consider that climate change might allow the spread of existing pests, for example, pests previously confined to glasshouses are already surviving successfully outdoors due to rising temperatures (e.g. glasshouse thrips). Some existing diseases might also thrive, such as those that favour humid conditions (e.g. mildews).

5.2 A Brief history of species introduction

The ice sheets began to retreat from Britain and Ireland around 18,000 years ago at the end of the last ice age, and with their removal came the return of people from their refugia in warmer parts of Europe. Around 6,000 years ago, a form of agriculture was being practiced that involved the introduction of livestock and crops, such as barley and common millet. Other useful plants were brought in and with this movement came unintended aliens, some of which were able to thrive in the rapidly changing landscape offered by extensive land clearance.

The Romano–British period, commencing in 43 AD, witnessed an escalation in the levels of trade in herbs such as rosemary and thyme and vegetables, including cabbage, onions and celery, grown for culinary purposes (van der Veen et al. 2008). Trees such as walnut and sweet chestnut also made their first appearance in Britain. As centuries passed the growth of travel, trade and commerce saw ever greater numbers of plants imported to Britain and Ireland, some for solely ornamental purposes. A number of these were able to naturalise in the mild climate and heavily disturbed habitats to which they were introduced.

When Europeans reached America in 1492 plants began to arrive from further afield than previously and the establishment of the East India Company in 1600 coincided with the expansion of trade from Asia and the age of international movement of plants on a large scale. Horticulture rapidly took over as the driving force behind new introductions and this reached its zenith in the late 19th and early 20th centuries with the activities of the independently funded agents known as Plant Hunters who were despatched far and wide in search of new garden subjects.

Though a steady trickle of alien plant material is still introduced to the UK by legitimate and illegitimate means, these days international legislation has greatly curtailed the free international movement of plants. Nevertheless, the consequence of earlier activity is that the number of species introduced for horticulture now massively outweighs those brought in for other purposes or by accident. The RHS Plant Finder includes around 72,000 entries accounting for somewhere in the region of 14,000 species, almost ten times the 1,568 species considered native to the British Isles (Stance, personal communication).

Cultivated plants, inside and outside gardens, are now a very important part of a landscape that has been radically altered since the postglacial recommencement of human activity. How this introduced element of the flora will behave in the future will greatly affect the appearance and ecology of the UK.

5.3 Niche Modelling

Predictions of which plant species might die out, do better or just carry on as normal under various climate change scenarios are based on the principles of bioclimatic niche modelling. Essentially the current distribution of a plant species is mapped against the climatic variables it experiences, such as average rainfall in July or minimum night temperature in January and a mathematical model is built that describes the range of climate experienced by the species now. There is substantial evidence that plant species tend to adhere to a particular set of climatic conditions. Examples of this in cultivation are the preference for cool moist summers in *Meconopsis* and the requirement for mild winters for the survival of *Dicksonia* tree ferns.

Perhaps the most comprehensive study of climate preference in a single genus of garden plants is the study of *Cyclamen* (Yesson & Culham 2006, Yesson, Toomey, Culham 2008) that produced niche models for all the species of *Cyclamen* then recognised. These studies suggest that most *Cyclamen* will be at increased risk of extinction in their natural ranges as climate progressively changes and that natural migration rates will not allow *Cyclamen* to move fast enough through natural seed dispersal to keep pace with moving climate. If modelling is correct, 11 of the 20 species studied will lose all their preferred growing area by 2050 and so be at very high risk of extinction. However, there is a role for British gardens in the future conservation of *Cyclamen* because the UK changes from having sub–optimal growing conditions for most *Cyclamen* to having ideal growing conditions for at least some of the species. *Cyclamen hederifolium* and *Cyclamen coum* (Fig. 5.1) are already naturalised locally in parts of the UK. This leads to the speculation that in future we might be going out in January and February to admire great sheets of bright pink *C. coum* among woodland trees rather than the current sheets of white snowdrops (another garden escape).

RHS / Anna Brockman

RHS / Carol Sheppard

Figure 5.1: (**Left**) *Cyclamen hederifolium* and (**Right**) *Cyclamen coum.*

Niche modelling is based around the preferences for species in nature. Garden plants are released from some of the constraints of growing in the wild. Key factors are 'aided establishment' such as growing seeds and young tender plants in greenhouses and putting them outside when they are older and more able to resist climatic extremes. Weeding, watering, soil improvement and many other horticultural techniques allow plants that could not compete with our native species to thrive in gardens. Sometimes these plants have a natural niche that is sufficiently close to one found in Britain that they can escape from gardens and become a menace. Japanese knotweed and *Buddleja* are such examples. As our climate changes it is likely that some species currently confined to our gardens will become more able to reproduce and spread in the UK. Many of our ornamental grasses are likely to fall in to this category.

The expansion of particular species could result in a dramatic change in character of the natural landscape. For example, there is a strong correlation between increasing winter temperature and the distribution of Chinese windmill palm *(Trachycarpus fortunei)* that has already been observed to expand into semi–natural forests in southern Switzerland (Walther et al. 2007). Currently in the UK, *T. fortunei* exists largely where planted for horticultural purposes, but in southern parts of the UK this species has begun successfully self–seeding in gardens and parks. This implies that rapid expansion could occur under scenarios for projected climate change and for the UK specifically, self–seeding is likely to become an increasingly viable means of expansion as winter temperatures are expected to increase. In addition, expansion via self–seeding is likely to expedite the migration of palms outside of the garden environment and could result in a substantial shift from the familiar 'British countryside' character of the natural environment. It is important to notice the distinction between climate change in facilitating the expansion of a species that appears 'alien' in comparison with the native vegetation of the UK, and climate change aiding the expansion of invasive species. Applying the definition of an invasive species, there is no published research to suggest that the palm will have major negative implications for the economy or ecosystem function in the UK.

RHS / Mike Sleigh

RHS / Tim Sandall

Figure 5.2: Chinese windmill palm (*Trachycarpus fortunei*) at RHS Garden Wisley.

5.4 Invasive non–native plant species

Rising temperatures have enabled non–native species to expand into regions in which they previously could not survive and reproduce (Walther et al. 2009). Some non–native vascular plant species have been shown to respond by flowering earlier per degree of warming than native species (Hulme 2011), indicating that non–natives could outcompete native species for resources under increased temperatures (Maskell et al. 2006).

The number of garden escapes that have already become invasive highlights the importance for gardeners to prevent the release of potentially invasive species from the garden environment. There are past examples of how the expansion of those species originally planted for horticultural purposes have changed the character of the natural environment, such as Himalayan balsam. This species was introduced in the early 1800s as an ornamental plant and relentlessly spread due to its easily dispersed seeds. Himalayan balsam outcompetes native species in ecologically sensitive areas, especially along river banks where it can grow in dense stands. These often impede river flow at times of high rainfall and in the winter, die back can leave the riverbank exposed and thus vulnerable to erosion (Day 2015). Fortunately such alien species with no close native relatives can sometimes be managed using introduced predator species.

It is likely that many cultivated non–native species that are disposed of by gardeners have so far failed to become established outside the garden environment due to climate constraints, however, there is the potential that in the future some of these species could become invasive (Hulme 2014; Dullinger et al. 2017). Examples of those which already have are presented in this chapter. As a matter of general principle it is always bad practise to dispose of any living garden waste in natural or semi–natural environments. It should be disposed of by green waste collection, composting or incineration as appropriate.

Extreme climatic events, such as storms and floods, will facilitate the spread of established non–native species through wind and water dispersal. Furthermore, the erosive nature of extreme climatic events will open new areas for colonisation and exacerbate the negative effects of invasive non–native species (Smart et al. 2014). Both general trends and extreme events are likely to cause native species to become stressed, putting invasives at a competitive advantage for the exploitation of important resources for growth (Sorte et al. 2013). However, there might be situations where non–native species will play a key role in stabilising soils and preventing erosion where native species no longer thrive.

5.4.1 Examples of non–native invasive species

The holm oak *(Quercus ilex)* is an evergreen tree native to the eastern Mediterranean but has become established in southern and eastern areas of England where it now regenerates freely in the natural environment, particularly in sandy coastal areas. Although the catkins provide a source of pollen for bees and insects, generally the holm oak is less valuable to wildlife than the native oaks, nor is it as susceptible to pests and pathogens which has facilitated the expansion of this species over native oaks (Woodland Trust 2016). The dense canopy of holm oak shades out native vegetation and there has been a call for this species to be listed on Schedule 9 (Plantlife 2010a). Not only is the holm oak more resistant to pests and diseases than native oaks, but its Mediterranean origin means that climatic conditions in the UK will become increasingly favourable to their expansion in the face of climate change. The evergreen nature of holm oaks means that the increasing dominance of this species over native varieties could compromise the inherent 'seasonality' of the British countryside.

However, not all non–native invasive species are entirely problematic. For example, the dense evergreen canopy of holm oak can provide year–round shelter for birds. It is also reasonably fast growing, which makes it ideal for public parks and gardens, helping to speed up the 'greening' of urban spaces. Being resistant to salt–spray, the holm oak has proved to be a useful windbreak in coastal situations, providing protection for the habitat behind it (Woodland Trust 2016).

Figure 5.3: Non–native holm oak (*Quercus ilex*).

Species already listed on Schedule 9 can be used to understand how climate change might shift the range of non–native species that are known to be invasive. For example, *Gunnera tinctoria* has become invasive in Ireland and has the potential to become invasive in England, Wales and Scotland where it is currently widely grown for horticultural purposes. The success of this species is due to the ability to exploit nutrient poor conditions through the symbiotic relationship with *Nostoc punctiforme*, a bacteria inside the rhizome of the *Gunnera* that allows nitrogen to be fixed from the atmosphere (Osborne et al. 1992). The ability of *Gunnera* to exploit nutrient poor conditions means that once established, it can become extremely invasive and expansion is expedited by the large leaves that prevent sunlight from reaching plants growing beneath their dense canopy. Historically, this species has been popular in large gardens due to its size, and is generally grown beside ponds in damp and boggy areas. As a consequence of climate change, the geographic range in which *Gunnera* might be successful is likely to shift to the north and east of the UK as much of the south and east becomes hotter and drier. The aesthetically imposing nature of this species will undoubtedly alter the character of the UK natural environment but perhaps more pertinently, will have negative consequences for native flora of the UK which could be outcompeted for both space and light (Plantlife, 2016).

RHS/ Jason Ingram

Figure 5.4: *Gunnera tinctoria* (centre foreground) in spring at RHS Garden Wisley.

Now we look to a non–native species that is known to be extremely invasive elsewhere in the world and that is beginning to show invasive potential in the UK. The hottentot–fig is a spreading succulent plant native to South Africa and grows in gardens in mild, maritime environments. It has become naturalised on walls and cliffs in these areas (Online Atlas of the British and Irish Flora 2016a). This species was listed on Schedule 9 in 2010 as small fragments of stem become established and grow rapidly – excluding the growth of other plants, lichens and bryophytes (Plantlife 2010b). Winter frosts in the UK limit the expansion of this species, however, populations are recorded in coastal locations across the UK (Fig. 5.5). This is an example of 'horizon scanning' for those species which might become invasive as a result of climate change.

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Figure 5.5: (**Left)** Detail of hottentot–fig (*Carpobrotus edulis*) and (**Right**) hottentot–fig on cliffs in Cornwall, UK.

Conversely, some species are known to be invasive but there is no legislation in place to limit their expansion. For example, New Zealand willowherb *(Epilobium brunnescens)* is a creeping perennial native to New Zealand that was introduced to Britain in 1904. It spreads both through wind borne seeds and through plant fragments which readily root. Favouring moist open areas, this species is becoming increasingly widespread in the hills of northern England, Scotland, Wales and even coastal areas of Cornwall (Online Atlas of the British and Irish Flora 2016b). Although not listed under any legislation, the spread of this species has reduced populations of native flora such as hairy stonecrop *(Sedum villosum)* (Braithwaite 2010) and, unless protective measures are put in place, this species will continue to spread.

To minimise the escape of potentially invasive species from the garden environment, it is important that gardeners distinguish potentially invasive species and garden weeds. Generally, a weed is considered to be a plant in the wrong place. For example, horsetail *(Equisetum arvense)* is a prolific weed in the UK and removal is destructive and often involves the application of weedkiller, yet this species is in fact native to the UK and arguably, horsetail is not in the wrong place at all. Conversely, Japanese horsetail *(Equisetum ramosissimum var. japonicum)* is a semi–aquatic *Equisetum* native to Japan and is a desirable horticultural aquatic plant chosen for its unusual tall and translucent stems which add interest to bog gardens and pond margins. This species is highly invasive and resistant to most herbicides and has consequently been prohibited from sale, commercial propagation and distribution in New Zealand. The temperate climate of New Zealand is relatively similar to that of the UK, therefore Japanese horsetail has the potential to become invasive in the UK if no legislation is in place to control its sale or distribution. It has been shown that to all intents and purposes, field horsetail is invasive in the sense that it is hard to keep out in the garden environment but would occur there naturally, whereas Japanese horsetail is a non–native potential UK invasive yet remains a highly regarded ornamental plant.

Regardless of climate change, there is a need to look closely at the potential of non–native ornamental species to become invasive. Gardens are exciting and challenging because of the cultivation of a wide range of exotic plants, and these in turn can have a role in sustaining other native species (Royal Horticultural Society 2015). However it is vital that there are clear boundaries between the garden and nature. If non–natives are increasingly imported for horticultural use, then there is a need for gardeners and professional horticulturists to be particularly careful in relation to the disposal of garden waste material into the natural environment. This risk is heightened by the increasing popularity of non–native seed mixes designed to persist over many years as self–seeding annuals.

RHS / Neil Hepworth

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Figure 5.6: (**Left**) Field Horsetail *(Equisetum arvense)* and (**Right**) Japanese horsetail *(Equisetum ramosissimum var. japonicum).*

5.4.2 Are some invasives native?

Currently, an invasive species is defined as a non–native that becomes a threat to the natural environment. We have shown that climate change is likely to enable some species to become invasive, however, climate change is also likely to facilitate the crossing of different species within a genus to form hybrids. Hybridisation can result in a fitter individual, which can sometimes be adopted as a cultivar and is probably tolerant of a wider variety of environments than either parent. As a result, hybrids can spread with vigour to the point where they become detrimental to the natural environment.

Rhododendron x *superponticum* is an example of a stabilised genetic hybrid that has become invasive in the UK. Many different species of *Rhododendron* have been introduced over the last two centuries, including species from the Himalayas and China. Hardier species tend to cross with less hardy ones, resulting in a much more resilient hybrid. For example, the 'ponticum group' is a collection of *Rhododendron* species that have been introduced since the 19th century; *Rhododendron ponticum* L. (Portugal, Spain and the Black Sea), *Rhododendron catawbiense* Michx. (eastern North America) and *Rhododendron maximum* L. (western North America). As a result of being grown together in gardens and nurseries, some particularly hardy hybrids have formed which are termed *Rhododendron* x *superponticum* (Cullen 2011). The resulting hybrid grows in dense thickets, blocking light to native species and rapidly colonise woodlands and adjacent open habitats. It is likely that a wider variety of 'exotic' species will be imported to the UK as a result of our warmer summers, thus this example raises the question as to whether climate change will facilitate hybridisations between imported 'exotic' species and existing relatives. Future research should consider the possible formation of potentially detrimental hybrids when determining the expansion of 'invasive' species.

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Figure 5.7: *Rhododendron* x *superponticum* – a native invasive?

5.5 Pests and diseases

The interactions between pests and diseases, their plant hosts and the environment have long been considered by plant health scientists. In many cases, climate change affects pests and diseases through their host species, such as through changes in their host's distribution, nutrition and defence capabilities (Dukes et al. 2009). There is a general notion that "warmer is better" for pests and diseases as in the absence of water stress, increased temperatures increase metabolic rate, reproductive rates and the likelihood of survival (Dale et al. 2014). Further, plant health is predicted to suffer under climate change due to the more frequent occurrence of extreme weather events, and pests and diseases tend to favour a physiologically distressed plant as defence mechanisms are weakened (Pautasso et al. 2012). For example, drought is expected to increase the incidence of tree pathogens due to the impacts of climate change on host physiology (Desprez–Loustau et al. 2006). Climate change is likely to extend the lifecycle of many pests and diseases, thereby reducing periods of dormancy. Rising temperatures may also allow the survival of pests and diseases previously restricted to glasshouses in the wider environment. Both of these outcomes are likely to result in the need for carefully considered biological forms of pest management (such as encouraging ladybirds which often act as predators) (Royal Horticultural Society 2017).

However, climate change can affect the distribution of pests and diseases regardless of host condition. For example, the reduction in frost due to milder winters removes a limiting factor for many pathogens, such as the causal agent of pine pitch canker *(Fusarium circinatum)* (Watt et al. 2011) and the geographic range of this species is likely to expand as a consequence. In contrast, some pathogens exploit frost wounds as a means to infect the host, such as the cypress canker *(Seiridium cardinale)* and in this case, a reduction in frost will lead to a reduced incidence of disease.

5.5.1 Pests and diseases affecting garden plants

An increase in the incidence of non–native pests and diseases could be the result of an increase in success of their host plant due to climate change. One such example is the powdery mildews, a group of fungal diseases affecting the foliage, stems and flowers of ornamental plants and grow by absorbing nutrients from the cells of the host plant. Many individual powdery mildew species have a narrow host range and are often identified initially based on their host species. Movement of plants, in part due to horticultural trade has allowed the spread of some of these species.

The high water content of powdery mildew spores means that they can infect plants in dry conditions (Royal Horticultural Society 2016b). Ornamental plants in southeast England will, in particular, experience water stress during certain times of the year. Therefore, it is entirely possible that we will see an increased incidence of powdery mildews as a result of climate change.

For example, *Heuchera* is a genus of evergreen, herbaceous perennial plants that, along with its associated powdery mildew, is native to the warm and dry Midwestern USA. Species of *Heuchera* are becoming increasingly fashionable due to their extensive array of foliage size and combination of colours. Symptoms of *Heuchera* associated powdery mildew were first observed in the UK in January 2015 at RHS Garden Wisley and it is likely that the disease spread within 12 weeks of the introduction of a symptomatic plant to an area of disease–free plants (Ellingham et al. 2016). By summer 2016 it was also reported at the University of Reading. Although powdery mildew is restricted to the locality of the plant host, this example illustrates how the spread of new pests and diseases can be rapid and that, without further research, the speed at which such introductions will continue to spread throughout the UK is not known. Nevertheless, it is important to consider the alternative argument: the presence of pests and diseases may prove beneficial in regulating the population of their host species where this is desirable.

In relation to pests, the rosemary beetle *(Chrysolina americana)* is an example of a nuisance species that affects non–native plants that are restricted to the garden environment, such as rosemary, lavender, sage and thyme (Malumphy et al. 2011). Initially, the range of the rosemary beetle was limited to London gardens but has recently become widespread across England and Wales. It remains unclear whether the expansion of the rosemary beetle has been expedited by climate change or rather, their host plants are becoming increasingly well–established throughout the UK due to rising temperatures. Alternatively of course, the spread of the rosemary beetle could be due to human transportation alone. Nevertheless, with the UK climate becoming increasingly suited to the successful growth of species such as lavender and rosemary, the distribution of the rosemary beetle could continue to expand in the coming years.

Figure 5.8: *Heuchera* associated powdery mildew.

Figure 5.9: Rosemary beetle (*Chrysolina americana*).

5.5.2 Pests and diseases affecting the natural environment

The present chapter has shown that there are some pests and diseases whose host plants are generally restricted to the garden environment, and therefore pose little threat to the natural environment. However, there are some pests and diseases that are introduced by horticulture whose host species form a key part of the character of the natural environment. For example, sudden oak death *(Phytophthora ramorum)* originated around the west coast USA in the 1990s, resulting in the mass mortality of some of their native oak species with symptoms including legions and bleeding cankers. The disease was first reported in the UK in 2002, spreading on ornamentals within the horticultural trade such as *Rhododendron, Viburnum* and *Camellia*, but also the common beech *(Fagus sylvatica)* and common larch *(Larix decidua)* (Denman et al. 2005). In the UK, the disease tends to be referred to as 'ramorum dieback' as our native oaks appear to be more resistant than their American counterparts.

The spread of this disease has in part been expedited by the invasion of infected *Rhododendron ponticum* (or *Rhododendron* x *superponticum*). However, *P. ramorum* favours wet and humid conditions as its dispersal mechanism is via spores produced on leaf lesions being 'splashed' between host plants in dense woodlands (Royal Horticultural Society 2016a). Therefore, it is likely that climate change will increase the vigour of this disease as winters become milder and wetter and, although summers will be warm and dry, periods of intense rainfall will create humid environments in woodlands. Currently, *P. ramorum* does not affect many species native to the UK, nevertheless, some have been established in the UK for many years and are not always considered native, yet still form an important part of the character of the natural environment, such as the common larch. Ultimately, regardless of heritage, the prolific spread of diseases come at a cost to both the environment and economy of the UK.

5. The interaction between the garden and the natural environment

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Figure 5.10: (**Left**) burning *Rhododendron* following outbreak of *P. ramorum* and (**Right**) the familiar dappled light of the common beech in the autumn.

Research into the spread of the oak processionary moth *(Thaumetopoea processionea* (Notodontidae)) in the UK has been of high importance in recent years. This species can cause damage to several species of oak trees, resulting in large–scale defoliation and bark stripping thus leaving the tree vulnerable to attack from other pests and diseases. Another concern is that the oak processionary moth (OPM) can be a risk to human and animal health by causing skin rashes, sore throats, respiratory difficulties and irritation to the eye. Although native to southern Europe, this species was introduced to the UK accidentally in 2005 where the initial distribution was limited to London but has since spread to West Berkshire, Surrey and Hertfordshire (Forestry Commission 2016).

In addition to commercial movements, there is evidence to suggest that the spread of the OPM is being expedited by climate change. Historically, OPM has not necessarily populated all regions occupied by its host species. It is more likely that the reason OPM has not followed their host–plant into all regions is due to factors such as land–use change. On the other hand, modifications in local environmental conditions have resulted in the build–up of high populations at their climatic limit and when conditions become favourable for expansion, it is believed that OPM can spread at a rate of 30 km per year (Groenen et al. 2012).

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Figure 5.11: Oak processionary moth. Images courtesy of the Forestry Commission.

As a final example we look at Dutch elm disease, a fungus that blocks water transportation systems in elms, thus causing branches to wilt and die. The disease was accidentally introduced to the UK from an unknown geographic location in the 1920s through the importation of infested elm logs (Brasier 2001). Currently, Dutch elm disease has not reached the northern limit of the elm itself with some remaining in Scotland, but generally these areas are considered under constant threat. The disease is spread through elm bark beetles, which tend to target mature trees (over 20 years old) and two major pandemics (in the 1920s and 1970s) show that the disease can wipe out entire generations, with subsequent recovery spanning several decades while trees regenerate from suckers (Potter et al. 2011).

The UK elm population is very diverse, with species including the English elm *(Ulmus procera)* and the field elm *(Ulmus minor)*. There is evidence that these and a number of other elm species were introduced to the UK before the Roman invasion, and are therefore considered native by some. Only the wych Elm *(Ulmus glabra)* is truly native. Although a diverse community, all elms are susceptible to Dutch elm disease to some extent. The UK elm population recovered in the 1990s following the pandemic of the 1970s, but the UK is believed to be in a 15–50 year cycle of regeneration and disease (Gibbs et al. 1994).

Whilst this example is not related to climate change, we illustrate here how regulating the means by which pests and diseases are introduced is of great importance to the protection of the natural environment of the UK. Climate change may expedite the spread of some pests and diseases through the creation of viable habitats as our climate becomes increasingly suitable for the growth of their plant hosts whether native, non–native or invasive. More critically, the impetus lies with the horticultural industry to take extra care in monitoring the health of the plants that are imported to the UK with the intention of avoiding the mass mortality of species important to the UK natural environment, such as the case with our native elms.

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Figure 5.12: An example of the devastating effect of Dutch elm disease.

5.6 The garden as a habitat

Regardless of the many threats that gardens can cause to the natural environment there are also many positive aspects of these managed green spaces. Cultivated ground is able to absorb and store water from rainfall, thereby reducing runoff during storms and in turn reducing flooding. Even the use of a permeable gravel drive versus impermeable tarmac increases the ecosystem service provided by a garden without loss of convenience and functionality of the space.

Functional components of garden management can also attract a remarkable amount of wildlife, for instance *Limax flavus*: yellow slugs that are highly beneficial as they feed exclusively on decaying organic matter in compost heaps. Woodlice, earwigs, earthworms and beetles are other species which breakdown organic matter whilst also providing a food source for hedgehogs, frogs and birds (Wild About Gardens 2013).

Plant choice is important to consider when attracting wildlife. An RHS study has shown that planting a mixture of flowering plants from different countries and regions is most effective for attracting pollinating insects. Whilst emphasis should be given to plants native to the Northern Hemisphere, exotic plants from the Southern Hemisphere could be used extend the growing season, as these tend to flower later in the season in comparison to northerly species. In general, the more flowers a garden can offer throughout the year, the greater the number of bees and other pollinating insects it will support (Salisbury et al. 2015).

In urban areas, domestic gardens account for a substantial proportion of green space and are therefore important for the maintenance of biodiversity (Gaston et al. 2005). Gardens with a variety of cultivated areas including lawns, shrubs and perhaps a vegetable plot offer feeding grounds to a range of birds, mammals, insects and other invertebrates (even including slugs!) that help sustain nature. Feeding tables for birds can help improve winter survival (RSPB 2009) and gardens provide nesting sites, both natural and through man–made nesting boxes (Chamberlain et al. 2004). Climate change might result in a mismatch of timing between a pollen/nectar source and the animals feeding on it (Chapter 6), however, garden plants chosen to provide a long flowering season have the potential to negate this, providing the animals can change host. Planting a variety of pollinating plants is also critical in sustaining bee populations which have been shown to be declining in recent years due primarily to climate change and land–use change; it is essential that bee populations are safeguarded due to their inextricable link to maintaining ecosystem health, crop production and food security (Potts et al. 2016).

Gardens also facilitate the movement of wildlife that is often critical for their survival, such as hedgehogs through gaps in fences and hedges. The provision of garden ponds which are kept topped up with water even in summer drought provides a source of drinking water to birds and a breeding ground to amphibians and other water dwelling animals. These water sources also provide 'stepping stones' for animals as they move through the landscape. We encourage gardeners to not consider their outside space as being in isolation, rather the connectivity of gardens is critical in maintaining wildlife and biodiversity.

The gardener therefore has the opportunity to make decisions in their garden that will help wildlife, such as keeping a lawn rather than hard paving, or growing a wider range of flowers throughout the season. These large areas of managed urban green space therefore offer a real positive value to the environment if managed carefully and thoughtfully.

RHS/ Jason Ingram

RHS/ Jason Ingram

5.7 Conclusions

The overarching conclusion of this chapter is related to the perception of invasive, non–native and native species. Some native species which are perceived as weeds are removed by gardeners and non–native species are planted in their place. This gives gardeners a great responsibility to ensure they keep garden plants in gardens and do not allow them to become future problems to nature. In terms of horizon scanning, it is also important to consider the possibility of non–native species from very different climates crossing to form a hybrid which proves to be extremely successful in the UK's changing climate, such as with *Rhododendron* x *superponticum*.

Both non–native and native species can act as host plants for a variety of pests and diseases whose introduction is generally a by–product of human action, but spread may well be exacerbated by climate change as illustrated by the oak processionary moth. Therefore, perhaps it is more pertinent to favour disease resistant species regardless of native status. Although there might be negative impacts, some non–native invasive species might actually fulfil a beneficial role to the natural environment, as illustrated by the holm oak example.

Nevertheless, the feedback loop between the introduction of a non–native species, the successful establishment to the point of invasion and the subsequent spread of pests and diseases is indeed an ecological problem in need of careful consideration. Research related to the interaction between the garden, the natural environment and climate change is at an early stage, however, this chapter has emphasised that both gardeners and the horticultural industry can reduce the likelihood of the spread of invasive species by responsibly disposing of waste, plant quarantine and health inspection, and adhering to environmental legislation such as Schedule 9.

Despite the many risks posed by garden escapes, from pests and from diseases, gardens have much to offer on the positive side of environmental interaction through moderating the impacts of extreme rainfall, high temperatures and local biodiversity loss. A well–managed garden can help the wider environment by providing ecosystem services as well as a place of beauty and relaxation.

6. Plant phenology and climate change

Webster, E and Hadley, P

6.1 Introduction

Greenhouse gas emissions are projected to rise for the foreseeable future and will continue to influence the climate (Kendon et al. 2016). To avoid extinction, plants will need to adapt to changing climatic conditions by shifting their geographic range, altering their genetic make–up (adaptive evolution) or changing the timing of growth and developmental events (known as phenology) (Parmesan et al. 2015). For plants in the natural environment, a shift in geographic range will allow some species to track suitable climate space, although this option will be limited in fragmented landscapes (Franks et al. 2014). Plants can adapt *in situ* through adaptive evolution, which involves the preferential selection of those with a genetic make–up most suited to the environment, such as taller individuals that can outcompete surrounding plants for sunlight. These individuals are able to survive to a reproductive age, thereby increasing the fitness and longevity of the population. This process occurs slowly and is likely to be outpaced by climate change. A much more rapid way for plants to adapt *in situ* is to change the timing of key lifecycle events, such as budburst (Nicotra et al. 2010). In the garden environment, plants cannot shift their geographic range and although human intervention can speed up the process of adaptive evolution (by cross–breeding, for example), altering the timing of lifecycle events is perhaps the most effective way for garden plants to adapt to changing climatic conditions. A shift in the timing of developmental stages has been noted by gardeners for many years (evidenced in Chapter 4 and Sparks 2015) and over the last few decades, these observed phenological changes have been linked to climatic factors such as rising temperatures (Last et al. 2012). The study of phenology is important ecologically, as measuring climate change in terms of flowering times, for example, can help us to understand if the timing of budburst will continue to coincide with the activity of important pollinators. Phenology is also important culturally and economically, as some festivals are based around the flowering of particular plants, such as the Thriplow Daffodil Festival, therefore projecting flowering times will aid the organisation of such events.

Geographic shift is discussed in Chapter 5 of this report, and the 2002 report provided an overview of the physiological basis of plant response to climate change. The present chapter focuses specifically on how climate change affects phenological events, by summarising recent literature and presenting analysed historical data collected from a selected number of garden plants by the late Nigel Hepper over a 60 year period from his garden in Richmond, Surrey.

6.2 A brief history of the study of phenology

For generations, people have recorded the annual cycle of the developmental stages of plants and animals, both in gardens and the wider landscape, often as an extension of their day to day diaries. Typically, recordings of budburst or the first appearance of flowers of native or garden plants, or the first appearance of insects such as butterflies and other easily observed seasonal phenomena were noted. The recording of phenological data goes back many centuries and includes long–term studies in which continuous measurements of yearly life cycle events have been recorded. For example, Robert Marsham and his descendants collected phenological data on more than 20 species from 1736 until 1958 (Margary 1926; Sparks et al. 1995; Tooke et al. 2010). Other data sets have been compiled which span many centuries, such as the flowering times of cherry in Kyoto which has been recorded since 705 AD (Aono et al. 2008). More recent long–term data sets of flowering of garden plants have been compiled in Last & Roberts (2012) covering a period from 1977 to 2007 in East Lothian and by Nigel Hepper (2003), covering a period from 1946 to 2002 in Leeds and Richmond.

6.3 Phenological mismatches

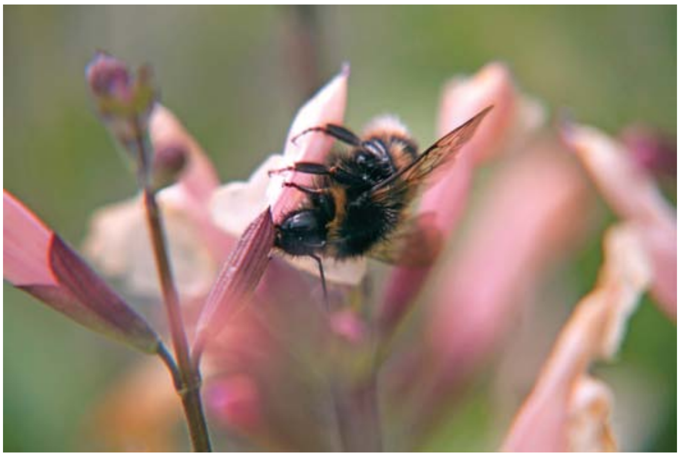
The significance of phenological research has increased more recently with the realisation that changes in phenology can lead to an asynchrony between interacting species, which is commonly referred to as a 'phenological mismatch', i.e. the flower is not open when the pollinator is active (IPCC 2014a). This can lead to a decline in species abundance and biodiversity (Defra 2012). Interactions involving species at pole–ward limits are particularly sensitive to changes in climate, such as *Selasphorus platycercus*, the Broad–tailed Hummingbird which migrates seasonally to follow 'nectar corridors' – delayed flowering due to insufficient chill days in some locations combined with earlier flowering in other areas may disrupt food sources and migratory routes for this and other similar species (McKinney et al. 2012).

As discussed in Chapter 4, climate change may impact on the incidence of pests and diseases. Gardeners will need to be even more vigilant than before for early signs of infection or infestations, and as climate change is likely to affect the biology of the pest/ pathogen as well as the host plants there may be some alteration in timings around when one could expect a pest or disease outbreak. For some species, milder seasons result in the advancement of plant development, and in many cases, the associated pest infestation period may also advance. For example, fifty years of aphid population data has revealed that the average first flight date has advanced by 0.6 days per year, with the influence of the North Atlantic Oscillation highly significant (Chapter 3) (Bell et al. 2015).

Natural predators of pests may also find themselves out of synchronisation with the population dynamics of their prey. Great tits/ blue tits for example are thought to provide a useful service to gardeners by preying on sawfly/ butterfly/ moth caterpillars, with predation being highest when feeding their own young (Mols et al. 2002). A disruption in the timing of these population peaks and troughs caused by climate change, however, not only critically affect the food supply for the young birds, but also the service these birds provide to the gardener. Mollusc populations are also regulated by predator/ parasite abundance, but some climate change models predict that some of the regulating parasites may suffer under a changing climate – for example the nematode

Phasmarhabditis hermaphrodita which parasitises slugs such as *Deroceras reticulatum* (grey garden slug) is less effective at controlling slug populations under warmer summer temperatures (Wilson et al. 2015).

Despite increasing confidence in global climate models and their associated projections, there are many unknowns relating to how climate change will impact on species interactions. Consequently, further research into the phenological response of different species is important in protecting our ecosystems and managing pest and disease outbreaks in the future.



RHS/ Tim Sandall

6.4 Methods for adaptation to environmental stressors

Plant phenology is driven by environmental conditions, primarily by day length (i.e. light intensity), temperature or a combination of both (Karsai et al. 2008; Caffarra et al. 2011). In the case of the former, budburst is triggered when daylight hours exceeds a species specific threshold. For the latter, budburst occurs when air temperature reaches a species specific threshold. This chapter will focus on those species whose phenology is driven by temperature, as the phenology of day length sensitive species are not affected to such a great degree by climate change. Although, it is possible that changes in cloud cover as a result of climate change will affect the phenology of day length sensitive species. Gardeners will be able to manage this with relative ease, by either moving day length sensitive species out of shady spots, by laying gravel in order to reflect light back up to the plant, or by planting taxa adaptable to this new environment. Recent evidence suggests that flowering time can be affected by other stressors such as water availability and herbivory. Climate change is expected to influence water availability but may also affect herbivory rates, as insect lifecycles increase and they are more active throughout the year. Water restriction has a variable affect on flowering time, whereas herbivory has been shown to consistently delay flowering (Jordan et al. 2015).

RHS/ Mike Sleigh

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Although temperature and day length influence the timing of growth and developmental events, it is important to note that climate change will also affect the efficiency of photosynthesis – the process responsible for turning the sun's energy into sugars and starch to support plant growth. This is discussed in detail in the 2002 report, and is mentioned only briefly here to maintain emphasis on climate change and plant phenology as opposed to growth efficiency.

6.5 Measuring the growing season

Earlier leaf emergence and flowering events indicate the extension of the growing season. The Met Office, for example, define the length of the growing season as the longest period within a year which begins at the start of a period of five successive days where the daily–average temperature is greater than 5.0°C, and ends on the day before a period of five successive days when the daily–average temperature is less than 5.0°C. A clear upward trend in growing season length is evident in Fig. 6.1 – in the late 19th century the Central England growing season was around 240 days and was a week longer by the 1960s to 90s. Further warming has led to the growing season being around a month longer than it was over the period 1961 to 1990 (on average). Although there is substantial year to year variation (Fig. 6.1), six of the ten longest growing seasons in the Central England Temperature record have occurred in the last 30 years (Met Office 2016a).

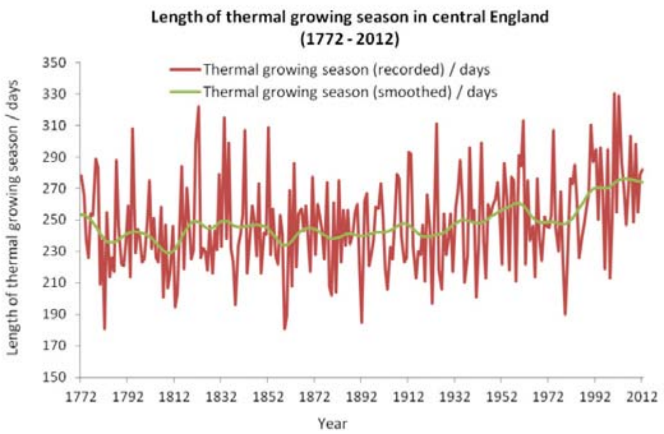


Figure 6.1: Growing season in Central England from 1772 to 2012 (red line). The green line shows data that have been smoothed to emphasise decadal timescale changes. Source: DECC 2013.

Growing degree days (GDD) is perhaps the most frequently used method to associate the timing of biological processes with the climate (McMaster et al. 1997). GDD provides a good relative measure of the growing season year on year. The aim of measuring GDD is to determine the amount of heat accumulated from a given point (usually January 1st) to the occurrence of a developmental phase, such as budburst. The amount of heat accumulated is typically estimated as the number of degrees above or below a specified baseline (usually 5–7°C) summed for each day (Roberts et al. 2015). In practice, GDD can be used to assess the suitability of a region to the growth of a particular species, to predict date of maturity or to help plan cutting and fertiliser application dates. Recent evidence suggests that the number of GGD in the most recent decade was 15% higher than the 1961 to 1990 average – thus, the growing season is getting longer (Kendon et al. 2016). Both the number of GDD and the extent of annual variation is region specific, as the south of England has almost double the number of growing degree days as Scotland (Fig. 6.2, left), and GDD tend to be above the 1981 to 2010 average in southern regions, and below the average in northern regions of the UK (Fig. 6.2, right).

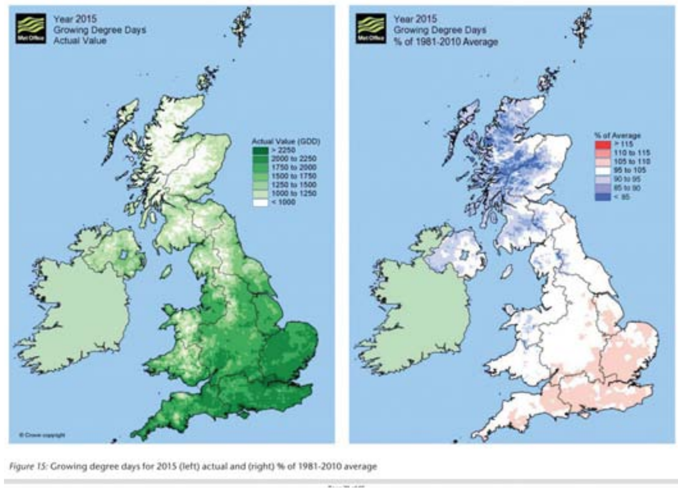


Figure 6.2: Number of Growing Degree Days in 2015 (**Left**) and percentage increase or decrease compared to the 1981 to 2010 average (**Right**). Source: (Kendon et al. 2016).

It is important to note that whilst GDD give a useful indication, its application in horticulture has been limited as it does not account for controlling factors on plant growth other than temperature, such as duration of radiation at a frequency available to the plant, day length and availability of nutrients and water (Russelle et al. 1984). Theoretically, heat accumulates gradually as temperatures increase over the spring, however, with temperatures projected to become increasingly erratic (so that the temperature on any given day is less predictable from the temperature the previous day), the required heat accumulation might still be achieved (by particularly hot days accounting for the deficit created by particularly cool days), but plants requiring consistently warm temperatures may not be able to flower, or flowering may be delayed by the occurrence of late frost events.

Some plant species require a minimum number of days below a certain temperature over the winter (known as a 'chilling requirement', 'chill days' or 'vernalisation requirements'), as opposed to depending on the onset of warmer temperatures associated with spring. Such species may inadvertently be interpreted as 'non–responders' if only GDD and/or first flowering time are considered (Cook et al. 2012). Recent evidence suggests that winters are becoming milder with fewer ground frosts, especially during November and December (Kendon et al. 2016). This will affect those species requiring chill days, such as soft fruits. Reduction in chilling will limit production and result in smaller fruits (Else et al. 2010), such as *Prunus* spp. Thus, whilst the growing season may appear to be extending according to GDD, it is perhaps more insightful to observe a variety of climatic variables to understand how climate change might affect gardening practice year on year.

6.6 The effect of spring temperature on plant phenology

The majority of data concern spring phenology (such as budburst), whereas autumn phenology (i.e. leaf fall at the end of growing season) is relatively under–recorded (Gallinat et al. 2015; Keenan et al. 2015). Less research has been carried out into the impacts of climate change on the phenology of fungi, with most studies focusing on flowering plants (e.g. Wolkovich et al. 2012). Fungi provide important ecosystem services by facilitating nutrient cycling, decomposition and soil aggregation. Fungal fruiting fulfils a similar role to the flowering of a plant, in that the fruit releases airborne spores for reproduction. The first fruiting date of fungus has become significantly earlier (9 days per decade) and the last fruiting significantly later (8 days per decade), indicating that organisms which support plant growth are also adapting to a changing climate (Gange et al. 2011).

RHS/ Jenny Denton

Much of the analysis of daylength insensitive flowering plants has shown that many have progressively flowered earlier over the last fifty years which is strongly correlated with an increase in average temperatures (Parmesan et al. 2015). Evidence indicates that the germination, fruiting, flowering and leafing of plants has advanced with regional warming trends (Menzel et al. 2006; Sparks 2015).

RHS/ Jason Ingram

Broadly, spatial variation in phenological response occurs across two spatial scales; some changes can be due to a latitudinal change in climate, whereas other changes can occur at a local level, for example in response to an urban heat island which advances phenological events in comparison to the countryside (Dallimer et al. 2016). In terms of future projections, leaf emergence could be 22 days earlier by 2100 if emissions continue at their current rate (Allstadt et al. 2015). However, some studies have reported a delayed spring onset and regional climate variation is one possible cause (Schwartz et al. 2013). For instance, it has already been observed that flowering time in the south of the UK is earlier than the north due to higher temperatures and climate change is likely to accentuate this difference (Kendon et al. 2016). Additionally, not all species respond to changing temperatures in the same way, as temperate woody plant species can rely on a combination of winter temperature, spring temperature and day length cues to control when to leaf–out in the spring (Polgar et al. 2011).

Some research has focused on the timing of phenological events for cultivated plants and a number of recent studies have confirmed that, for many garden plant species, changes in average temperature is the key factor affecting the time of flowering (e.g. Last & Roberts 2012). The same species have been analysed separately using the individual data sets of Nigel Hepper (section 6.2) and Fred Last (of the Royal Botanical Gardens, Edinburgh) and there was a clear consistency in the degree of advancement in flowering time for an increase in temperature of 10°C (Hadley, unpublished).

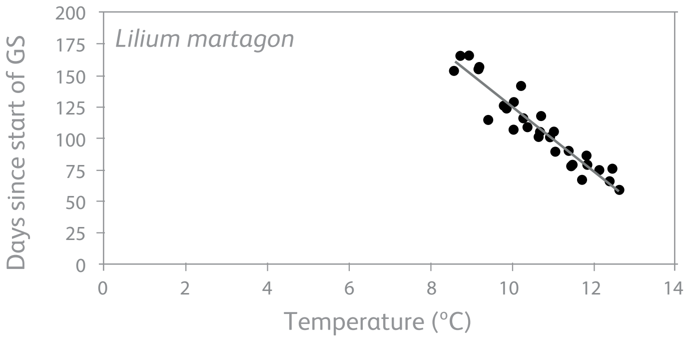
Here, we examined the flowering times of two common garden plants taken from Nigel Hepper's data set (recorded at his garden in Richmond and in Kew Gardens) and compared them with temperatures recorded over the same period at Kew Gardens. The growing season can be calculated in a variety of ways (section 6.5). In this case, the beginning of the growing season was considered as the time when the daily temperature remained above 7°C for five consecutive days and the average temperature from the beginning of the growing season to the day when the first flower was recorded for each species was calculated. The data show that the flowering time of *Malus sylvestris* and *Lilium martagon* is advanced as a result of increasing temperature (Fig. 6.3 and Fig 6.4).

Using detailed statistical analysis, other studies have confirmed that flowering time is most sensitive to spring temperatures as opposed to the temperature of the preceding autumn and winter (Sparks et al. 2000). Although there are some exceptions, as similar analysis has found that the flowering time of the autumn crocus, for example, is delayed by high summer temperatures, but this delay is offset by the advancement caused by rising temperatures in the preceding autumn (Sparks et al. 2000). Such studies have provided overwhelming evidence that climate change is causing earlier flowering, but future research is required into the possible consequences of this observation.


RHS/ Graham Tichmarsh


RHS/ Carol Sheppard

Figure 6.3: *Malus sylvestris* (**Top**) and *Lilium martagon* (**Bottom**).



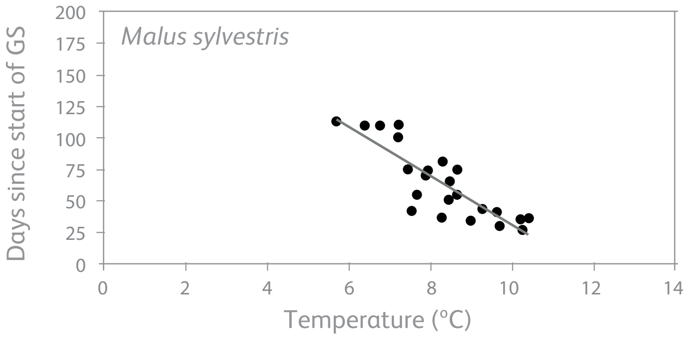


Figure 6.4: The relationship between flowering time (days since start of the growing season, see text for definition) and temperature of two common garden plants based on data collected by Nigel Hepper at Kew Gardens since the 1960s (unpublished).

6.7 Possible implications of reduced chilling

Many perennial herbaceous and woody species require a period of winter chilling, before rapid growth takes place in the following spring. Winter chilling refers to a prolonged period where air temperature remains below a fixed value, which is usually around 7˚C but can be species specific. This is a feature of tree fruits in particular, as these species require a period of winter chilling to ensure adequate flowering and fruiting the following year. There is concern that increasingly mild winters may lead to an insufficient cool period for those species requiring a relatively large winter chill period, such as blackcurrants. Chill requirements vary between species, for example, apples have a chill requirement of around 200 to 1500+ hours, whereas almonds have a chill period of just 100 to 500 hours (Else et al. 2010).

Spring temperature is still important for those species requiring a chill phase, as rising temperatures are required to 'force' bud break and flowering. Forcing bud break depends on the amount of chilling received: the longer the chill period, the lower the heat requirement for bud–break. In practice, this means that a reduced chill period requires more heat in the spring, and the increasingly erratic patterns in temperature projected may not provide these conditions. Erratic temperatures over the winter might also result in the switching between chill periods and 'forcing' periods, potentially inducing a substantially earlier budburst.

Analysis of over 20 years of flowering data for walnuts grown in California showed substantial changes in the pattern of flower and leaf emergence resulting from warmer winter and spring temperatures (Luedeling et al. 2012). However, a preliminary study of flowering responses of a number of apple varieties at RHS Wisley Gardens remains inconclusive, with further research required to determine the possible impact of rising winter temperatures over the last 50 years on flowering time. It is possible that despite rising winter temperatures, the UK climate currently still provides a sufficient chill period for those species that require it (Pagter et al. 2013).

As a decline in consistent periods of chill time over the winter is expected for many parts of the UK, fruit crops with a lower chilling requirement will need to be selected or alternatively (particularly in lower latitudes) a shift towards cultivating fruits from a warmer environment will need to be considered. For instance, grape vine production has benefitted from the gradual warming of the UK climate over the last few decades and this crop will certainly benefit from continued climate warming in the future (Spellman et al. 2002). Butterfield et al. (2000) simulated the effect of climate change on grape vine production in the UK and showed that budburst would occur 10 to 25 days earlier under future climate change conditions in the UK, while maturity could also occur earlier so that areas suitable for growing grape varieties could extend from southern and central counties of England to Lancashire in the west and Humberside in the east. Yields are also predicted to increase by 10 to 25 % and quality for wine making is also predicted to increase. There is also more potential for growing table grapes in the UK under polythene, as well as opportunities for the cultivation of stone fruits such as peaches and apricots. In fact, the first commercial plantings of apricots have already been made in southern England. The prospects for these as new crops for the UK are likely to increase in the future, although these species flower early in the season and varieties being trialled currently in the UK can be damaged by those late frosts which are predicted to occur with a similar frequency under conditions of climate change (Slingo et al. 2014).

6.8 Conclusions

Rising temperatures during spring and autumn suggests that the growing season is extending (Kendon et al. 2016) and there is extensive evidence to suggest many plants are responding by flowering earlier. Growing degree days is one approach to quantifying the growing season and, whilst this is extremely useful in understanding what species are suited to a particular location, it does not account for the limiting effect of extreme weather events on plant growth, especially the occurrence of late spring frosts. Gardeners will need to be in tune with the microclimate of their garden, in essence understanding when those late frosts might occur and taking steps to mitigate against the damaging effects (such as insulating tender species). A longer growing season also implies that there will be insufficient chill days for those species that require it, such as soft fruits.


RHS/ Carol Sheppard

7. Garden management and design within a changing climate

Cameron RWF, Clayden A and Hoyle H

Gardens are sometimes seen as microcosms of a wider world, reflecting changes in attitudes and fashions. As such they are likely to be influenced by indirect factors due to climate change as well as direct influences. These indirect factors are difficult to predict and may be driven by economic and social–cultural changes as much as environmental aspects – for example a move to cultivate a greater proportion of fresh fruit and vegetables at home may reflect a change in global food prices, if commercial cropping becomes less reliable. Similarly, increased migration due to climatic changes in the Mediterranean basin or Sub–Saharan Africa, may result in a change in housing policy, with densification of housing and less space for gardens. Conversely, improving the quality of life for urban citizens through 'climate–proofing' cities may result in a renaissance in gardens and green space as their value in mitigating storm water run–off, urban heat island effects and improving air quality becomes more apparent (Fig. 7.1). This chapter begins by re–capping key climatic features of the UK, before the role of gardens in climate mitigation and their importance in urban environments is discussed. Finally, climatic influences on plant development and garden style are presented followed by garden design and plant strategies for gardening in a changing climate.

Figure 7.1: As the effects of climate change take hold, will we value urban green spaces more for the services they provide.

7.1 Key climatic features for the UK

The current and predicted trends associated with climate change are outlined in Chapters 2 and 3. These are likely to influence how we see the domestic garden in the UK, the future design of gardens and how we manage the plants and structures within the garden. Using trends to date and the medium emissions scenario it is worth summarising what the key relevant points are from Chapters 2 and 3, namely:

- Mean temperature is projected to increase in all seasons and all regions of the UK.
- There is less certainty around precipitation but this is projected to increase in winter and decrease in summer, although some projections show a small precipitation increase in summer.
- Despite these predictions high year on year variability in rainfall will continue.
- Less cloud cover in summer suggests solar radiation will marginally increase compared to current levels.
- Modest increases in the frequency of dry spells (e.g. 10 days without rain) are likely across much of the country with more substantial increases in the south and east associated with lower summer rainfall.
- The frequency of wet days (with rainfall greater than 25 mm) is likely to increase in winter. In general, wet days will increase by a factor of between 2 and 3.5 by the 2080s over most of the lowland UK.
- Increases in temperature and less summer precipitation are likely to increase the likelihood of drier soils in spring, summer and autumn.
- The expansion of arid 'agroclimatic zones' indicate a significant increase in the risks from dry soils and drought and an increased need for irrigation.
- Effects of climate change and natural shifts in climatic patterns may impact on the dominant weather masses that affect the UK, for example shifts in the position of the jet stream. A potential consequence of this in an increase in the severity of storms experienced and more variability in climatic patterns in future.
- Coastal areas are likely to see a mean year on year increase in sea level rise of 1 mm.
- Extension of the growing season, but residual or perhaps even greater variability in weather patterns such as 'unseasonal' frosts or dry periods may impact on garden plant development, and influence pest and disease incidences.

7.2 Climate change mitigation and adaptation

7.2.1 The role of garden design and management

In the future, gardens are likely to have an important role in helping mitigate against the effects of climate change. This may be through a change in management that reduces greenhouse gas emissions, or activities that help fix (sequester) atmospheric carbon into the soil. Indeed, gardens which have by and large been seen as under the domain of the private individual, may increasingly be influenced by legislative processes that enforces transition to a more environmentally sustainable way of life (see section below about wider urban green space). Already gardens are beginning to be valued not only as places for recreation and aesthetic designs, but also for the wider benefits they bring urban society (ecosystem services) (Cameron et al. 2016). This includes their contribution to:

- Localised cooling and helping reduce the urban heat island effect.
- Saving energy use in buildings by insulating against cold draughts and heat loss in winter, through the creation of shelter belts and insulating wall shrubs/ climbers.
- Reducing reliance on internal air conditioning within buildings in summer by shading buildings and providing cooling through evapotranspiration and an enhanced albedo effect (reflecting more solar irradiance back into the atmosphere) (Fig. 7.2 and 7.3).
- Reducing the risk of urban flooding through capturing rainfall, improving infiltration to the soil and reducing surface run–off.
- Storing atmospheric carbon as soil carbon.
- Reducing the carbon footprint around food, by encouraging more home production.
- Providing habitat for wildlife, and conserving urban biodiversity.

Figure 7.3: Research has indicated that some species, such as *Stachys byzantina* are effective at cooling their immediate environment, through in this case relatively high evapotranspiration rates and reflecting solar energy back out to space (i.e. a high albedo) due to the pale colour of the leaves (Vaz Monteiro et al. 2015).

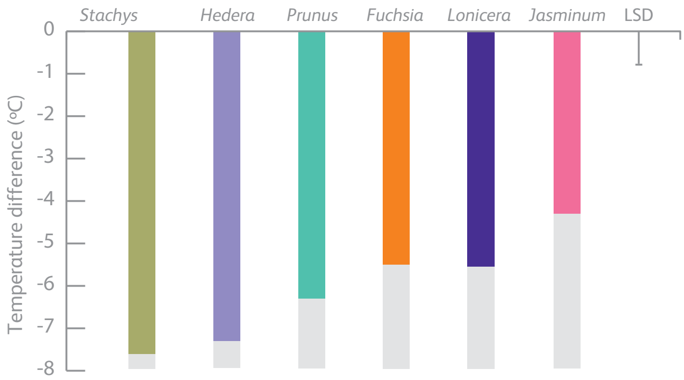


Figure 7.2: The extent to which different plant species can provide cooling to a building wall. The use of plant screens can reduce the amount of solar irradiance impacting on a building, thus reducing the requirement for artificial air conditioning. Comparison of a range of wall shrubs/ climbers with *Stachys* as a comparison (Cameron et al. 2014).

One drive for global climate change mitigation is to increase the soil's capacity to store carbon. In a garden context, soils tend to be more resilient as their organic matter percentage (i.e. carbon) increases – water infiltration and aeration in clay soils is improved, and moisture retention in sandy soils is enhanced as organic matter proportions increase. Higher soil temperatures, however, accelerate organic matter breakdown and reduce humus content. Warmer, drier summers may therefore result in the gardener having to make greater efforts to maintain organic matter content in the soil (and the associated advantages on soil structure). Rapid changes in temperature and soil moisture status also seem to result in rapid releases of carbon from the soil, both factors are likely to increase with more turbulent weather patterns (Reichstein et al. 2013).

Changes in garden management and the garden industry might also include:

- A move to more sustainable sources of energy – solar powered lawn mowers or green electricity mowers replacing petrol driven ones.
- Increase in home composting – both to reduce energy costs with waste disposal, but also as an alternative to artificial fertilisers with a high level of embedded carbon.
- Restriction in outdoor heaters that use non–sustainable fuels.
- More use of captured rainfall water rather than potable water. The requirements for potable water to be of drinking quality result in large investments in energy both to clean but also transport (pump) water across the water grid.
- Greater restrictions on the use of hosepipes and power–wash patio cleaners during prolonged dry/ drought periods.
- The implementation of more efficient drip irrigation systems for glasshouses and parts of the garden that have a high water requirement.
- Pots made of recyclable plastic or other materials that are biodegradable.

- Ethically sourced timber that is not derived from virgin rainforest, or comes from sustainable forestry schemes.
- Reduction in peat use, as degraded peat bogs release carbon dioxide.
- A greater use of locally sourced plant material to reduce energy associated with transport – greater use of transport hubs by industry to improve the efficiency of distribution.

7.2.2 The role of urban green space in climate mitigation and adaptation

Looking beyond the domestic garden and out into our surrounding neighbourhood spaces and parks; climate change alongside other initiatives around food security and the dramatic growth in demand for allotments has the potential to reshape these landscapes and to enable greater community involvement.

As has already been discussed, the domestic garden can make a positive contribution to managing storm water run–off in a discrete manner, but there will be greater efficiencies if the application of sustainable urban drainage systems (SuDs) can be extended into the public realm. Here storm water management techniques that include: retention and detention ponds, swales, porous paving and an increase in vegetation can make a more significant impact on reducing the likelihood of flooding. Figure 7.4 shows a pedestrian street in the residential suburb of Billencourt in Paris. Running alongside the front of the apartment blocks is a swale, which transports rainfall from the adjacent roofs and courtyards into the retention pond in the nearby park. Residents access their apartments via the small bridges that straddle the swale. Here, the water is treated through bio remediation before being released into the River Seine. As city authorities look to increase the amount green infrastructure to deliver greater environmental and social benefits (ecosystem services) it raises issues around who will take on the responsibility of maintaining these spaces. This example illustrates a new opportunity for residents to help shape and maintain the public realm whilst also improving the threshold to their homes. These opportunities may also extend into the local park where potential water storage areas create habitats where alternative plant communities may thrive (Fig. 7.5).

Figure 7.4: Billencourt, Paris – Residents cross a swale to access their apartments.

Figure 7.5: Retention pond in Billencourt, Paris.

In new residential developments there may also be a shift in the balance between the proportion of private garden space towards larger communal areas that incorporate SuDs (see points below regarding legislation changes) but may also include small allotment areas that are easily accessible to local residents. By keeping these areas in the public realm there is not only an advantage of scale, in terms of the amount of planting and potential to include SuDs, they may also be less vulnerable than the domestic garden to those situations where mature trees may be removed and front gardens paved over to create off–street parking.

Despite the tradition in recent years of *private* gardens around high density housing schemes within the UK, as more emphasis is put on adaptation to climate change in city/ town centres, the need to link up green spaces (i.e. develop an integrated green infrastructure) and improve its effectiveness in meeting a range of environmental problems, may result in a transition to more public green space.

Or even semi–public green space – owned by the local authority but managed by the residents. These models are common on the continent. In Munich, Germany communal allotment spaces can be at the heart of residential developments (Fig. 7.6 and 7.7). Such designs help the management of storm–water flows as well as provide wider social and cultural benefits.

Figure 7.6: Allotment spaces are used to improve community interactions and help deal with environmental issues such as storm water management, near to residential areas. In this case in Munich, Germany.

Figure 7.7: A swale is used to gather surface water from the residential area, and allow it to percolate slowly into the main drainage system. This reduction in the rate of surface water run–off allows the main drain systems to better cope with intense rainfall events.

Similarly in Paris, France where residential areas are typically even more densely populated and there are very few private gardens, community groups have come together to acquire small areas as shared garden space for growing plants, herbs and vegetables (Fig. 7.8). Parks in Paris are also being adapted to provide small allotment spaces, typically no larger than one or two square metres, where residents who do not have access to a garden may grow cut flowers and some vegetables (Fig 7.9). Each of these examples show new opportunities that may emerge as cities attempt to adapt to climate change enabling residents to play a more proactive role in shaping their local environments.

Figure 7.8: Communal garden in Paris, France. Although communal gardens are less common in the UK, the design of private gardens in future may be influenced to a greater extent by the need to provide ecosystem services to the surrounding residential areas.

Figure 7.9: Small allotment gardens provide gardening opportunities for local residents (Park Martin Luther King, Paris) but also green corridors for wildlife and multi–functional landscapes where storm water can be directed in times of need.

7.3 Garden character in response to climate change

7.3.1 The effect of climate change on garden style

Climate change will influence plant development (see Chapter 6) and garden style. The magnitude of climatic changes to which a garden is likely to be subject will depend on regional location and local topography. The western parts of the UK have historically had higher rainfall patterns and this is likely to be maintained, but further severity of winter storms may increase the likelihood of flooding. Lower summer precipitation and higher rates of soil moisture evaporation will increase the incidence of drought stress, especially in the east, and particularly in London and the Home Counties. Gardens on hilltops are likely to suffer more from drought, while those in valleys or on flood plains will be susceptible to flooding. Gardens by the coast or in broad low–lying river valleys and coastal plains, e.g. the Norfolk Broads, Somerset Levels, The Wash or the Humber Estuary will feel the impacts of rising sea level and more intense and frequent tidal surges. This combined with increased storm intensities may result in greater coastal erosion with implications for gardens situated on soft clay, shales and chalk soils around exposed coasts.

It is not only geographical location that influences the character of the garden; personal preference, primary use, lifestyle as well as underlying edaphic (i.e. soil influenced) and biotic factors all affect design, management and the types of vegetation/ species that will thrive. In the domestic garden, the design and content result from a complex interplay between what is available and what is considered desirable. The garden layout often evolves year by year and may undergo radical changes from time to time, not least when a property comes under new ownership. Gardens range from the highly functional on the one hand – a place to house the dog, entertain the children, provide an outdoor eating area to the highly aesthetic on the other hand – colourful and diverse flower borders, rich in ornamentation or landscapes that closely follow a particular theme or fashion – cottage garden style, naturalistic, semi–formal, woodland style etc. Such typologies themselves will influence the 'vulnerability' of the garden to climate change related events. The garden with the concrete patio, utilitarian lawn and sycamore tree *(Acer pseudoplatanus)* in the corner, will be resilient to a flooding event, and be fully functional again a few days after the waters have receded. Conversely, the garden with the alpine scree bed and steppe–like dry meadow may take much longer and require more expenditure before it regains its former glory. Many gardeners are content to utilise plants that are well adapted to their garden's climatic conditions (82% in the survey, Chapter 4). To some extent this may reflect the traditional 'benign' nature of the UK's climate and the fact that so many plants from the world can be grown successfully in the British Isles. In more arid geographical regions such as Australia and southern USA, there is greater contingency placed on providing irrigation to support plants that would otherwise die, although attitudes are changing with 'better–adapted' native species coming to the fore in more recent years (Sovocool et al. 2006; van Heezik et al. 2012). Over 60% of respondents in Chapter 4 suggest they do not like growing *difficult* to cultivate plant species, but that leaves a significant minority that do. These will be the gardeners that will face the greatest challenges due to climate change, but also the ones likely to go to greater lengths to ensure their 'prize specimens' do not succumb to extreme or atypical weather events. There may be some positive outcomes too for those gardeners that beforehand have attempted to grow plants at the limit of their natural temperature tolerances. A 1–3°C increase in mean winter temperature may increase the feasibility of some species to survive winter (if still protected from occasional incidences of frost) and 1–4°C enhancements in summer temperatures will allow for a greater accumulation of energy (photosynthates), which ensures a plant's long term survival. Each species has an optimum temperature for photosynthesis, and for those genotypes from tropical or warmer summer continental climates this optimum temperature tends to be higher than those that normally experience cooler summers. Those keen gardeners that enjoy growing plants at the edge of their temperature tolerance range are likely to see greater chances of success, especially if warmer conditions throughout the year are aligned with a longer growing season and some increase in solar irradiance in summer (Fig. 7.10). Higher winter temperatures will allow more 'tender' cold/ frost sensitive species to survive (for example allowing a greater range of *Fuchsia* cultivars to come through the winter), but also higher summer temperatures may increase the probability of a wider range of trees being grown from the English Midlands northward, as well as new genotypes being introduced to southern counties. As successes increase, so will the demand. Sought after plants may cease to be the province of specialist nurseries, and may become available in garden centres and adopted by the wider gardening fraternity.

Figure 7.10: *Lampranthus brownii* and cultivars have become more popular in recent years, and the likelihood is that more will successfully overwinter, and their range will increase across UK gardens in future.

A counter–balance to this however, is if one consequence of climate change (in the intermediate future at least) is greater variability in weather patterns, then those species that are closely aligned to strong and predictable seasonal stimuli may struggle to establish. This again will affect trees and other woody plants derived from continental climates particularly – where transitions from typical winter to spring and summer to autumn weather conditions occur over a week or so rather than a month or two which might be more typical of a maritime temperate climate such as the UK. Climate change may accentuate these 'indecisive' springs and autumns, predisposing plants to more stress if they do not match physiological processes (e.g. bud break and reductions in cold hardiness) to actual weather events (e.g. leafing out before the last frost of spring has occurred). Variability in the weather has always challenged UK gardeners, but this aspect may get worse and lead to frustrations when attempting to grow some species. Survival may not be the only issue – poor garden performance year on year, for instance a lack of spring blossom or consistent autumn colour may lead to some genera losing popularity. Other species however, will show resilience and a dynamic and flexible approach to plant choice will, by and large, retain a dedicated gardener's interest. Those showing less flexibility for example, advocates of immaculate, well–watered lawns and 'Edwardian' herbaceous borders (where many plants require staking even just to support their own weight, irrespective of the effects of heavy rain and wind), may have their 'work cut out' to maintain standards.

Warmer temperatures and a prolonged growing season have already been linked with a decrease in flowering in some plants and an increase in vegetative growth (Martin 2015). Dawyck Botanic Garden in the Scottish Borders have noted rampant growth in mild years with species such as *Astilbe*, *Hosta* and *Rodgersia*, as well as some ferns, not to mention the increase cutting requirements for the lawns. Indeed, it is now not unusual for lawns to be cut in every month of the year in a good number of the UK's heritage and botanic gardens.

As discussed in Chapter 5, the interactions between plants, pests and beneficial predators of the pests are complex, and gardeners may see some favourite plants do better in these complex 'arms races', and others do worse as the climate changes. A prudent approach to garden design is to include some diversity in the landscape (water or bog gardens, drier slopes, patches of light and shade etc.) and ensure a fairly wide range of plant types are being cultivated. This increases the opportunities (ecological niches) for wildlife and encourages a wider range of beneficial organisms (e.g. predatory insects, birds, amphibians and small mammals such as hedgehogs) which help control pest species in general.

7.3.2 The design and use of the garden in a changing climate

The prospect of milder winters, longer summers and an extended growing season may encourage gardeners to think differently about how they design and use their gardens in future. It is an opportunity to spend more time outdoors, tending the garden and socialising with family and friends. It may also encourage homeowners to think differently about the connection between our indoor and outdoor spaces as we adjust to a more fluid transition between these two environments where there is not quite the same pressure to keep the doors and windows firmly closed against the cold (Fig. 7.11). However, unlike much of southern Europe, which has traditionally embraced an outdoor lifestyle of cooking, eating and socialising on the garden terrace or patio, climate change in the UK also brings with it the prospect of wetter winters and more intensive periods of rainfall in summer which may deter garden users from planning too far ahead for the family get together or the barbeque with friends.

Figure 7.11: Does a warmer summer mean the garden becomes an extra room, with plants largely playing the part of the surrounding décor?

Gardeners might therefore find ways of responding to this opportunity by creating covered spaces either within the garden or possibly connected to the house where there is shelter from a sudden down pour, whilst still allowing for the business of preparing food and enjoying the sounds and smells (fragrance) of the garden. These structures might be simple temporary awnings or 'shade sails' that could be attached to the house or even strategically planted trees or simple pole structures on which climbing plants are trained. Alternatively they might include more permanent verandas or buildings that provide shelter throughout the year. Either way they will be less expensive to build and maintain than a conservatory whilst enabling more access to the garden. Figure 7.12 is an example of a small timber frame building and veranda set within the garden. The building incorporates a green roof and rain capture system which feeds rainwater directly into the adjacent pond which then overspills into a small wetland and soak–away. It demonstrates how new physical structures might be combined to create sheltered areas but also afford space for plants and provide a range of different habitats from dry to wet within the one garden. Such small–scale interventions may provide new opportunities to explore different planting combinations, including more naturalistic styles or providing interest that extends into the winter months. Shelters with adequate levels of light will facilitate temporary or more permanent enclosures where less–hardy plants can be stored over winter. These structures might also function as useful outdoor workspaces in wet weather for potting on plants or even drying clothes when there is the threat of unpredictable rain showers.

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Figure 7.12: Garden building incorporates a veranda, providing an outdoor work or seating space in wet weather. The building is also used to manage rain water which is fed directly into the adjacent pond.

This example also demonstrates how at a very local scale the domestic garden can make a contribution to managing storm–water runoff by isolating itself from the combined sewage and drainage network and enabling water from roofs and other surfaces to dissipate more slowly through groundwater into streams and rivers. By adopting this approach there is an opportunity to further animate our gardens by including ponds but also to increase the range of habitats for different fauna, which may also help in controlling garden pests.

7.4 Garden management in response to climate change

7.4.1 Dealing with warmer summers and increased risk of drought

Mediterranean planting

For gardens in the south/ southeast /east, especially drier summers will pose the risk of drought. Drier summers will provide genuine horticultural opportunities as well as constraints. Species from Mediterranean climates could be utilised more frequently in an attempt to deal with summer soil moisture deficits. As some Mediterranean species can tolerate a few degrees of frost, these are likely to be perennial features even if winters do not become entirely frost–free. Heavy winter precipitation should also not prove problematic, as long as free draining capability is ensured since Mediterranean climatic regions have significant levels of winter precipitation, but the soils themselves are often rocky and free draining. Mediterranean species are well–adapted to drier climates due to adaptations such as hairy leaves (pubescence) that reduce wind speed over the leaf surface and trap moist air. Translucent hairs, too, provide the plant with a pale hue increasing light (and hence heat) reflection away from the surface. Thick waxy leaves help reduce moisture loss directly through the leaf cuticle and stomatal pores (pores located on the underside of the leaf) may be fewer in number and/ or located in sunken pits, again to prevent moist air being removed rapidly from the surface of the leaf. Localised raising of humidity around the leaf reduces the gradient in the transpiration stream, leading to less water loss from the leaves. Root distribution also helps with drought survival – some species invest in a deep tap root to explore moisture reserves down the soil profile, whereas others have a fine network of surface roots to absorb water from light rainfall, to capitalise on those occasions where only the surface part of the soil profile becomes moist.

Plant strategies for dealing with water stress

In garden plants, even in non–xerophyte species, strategies for survival and success can vary radically when plants are exposed to moisture deficits (Cameron et al. 2008). Plants run a risky balancing act in that they need to open the stomatal pores on their leaves to absorb CO_2 and thus drive photosynthesis that allows them to grow (and in a competitive plant community compete for light), but at the same time these pores release water vapour as part of the transpiration stream. This transpiration enables essential nutrients to be translocated from the roots to the growing shoots, but also means the plants lose water, and when water supplies in the soil become limited, they run the risk of injuring their tissues through desiccation. Different plant species vary in their strategies to allow them to remain competitive in their natural environments. For example, *Forsythia* x *intermedia* continues to grow, maintaining open stomata even when soil moisture starts to become limited, thus risking damage to its leaves and stems (it adopts this strategy on the basis that, due to its natural fast growth rate, it can re–grow once moisture becomes available again). *Cotinus coggygria* (Fig. 7.13) on the other hand regulates stomatal closure very much in line with soil moisture availability – closing quickly when roots perceive a dry soil, but also opening equally rapidly when moisture returns, even if this re–wetting is temporary. In contrast, *Cornus sericea* adopts a more conservative strategy. This species and its cultivars close stomata very rapidly when perceiving a drying soil, but these then remain effectively shut until the soil returns to a consistently wet status. *Hydrangea* cultivars do something similar, and it can be many weeks before growth recommences after even a relatively short drought period. Many garden plants may also alter some of their strategies too as to when they open their stomata and maximise photosynthesis when under a warmer/ drier climate. Greatest rates of photosynthesis are likely to move towards cooler periods of the day, e.g. early morning or late afternoon, rather than between mid–day and early afternoon, primarily as a water conservation measure. Gardeners can help plants with their water saving capacities, for example through greater use of shade and windbreaks in the design of a garden in an attempt to relieve plants from excessive heat stress and moisture loss.

Greater moisture deficits in summer in southern, southeastern and eastern regions of the UK, will prove challenging to certain tree species and their cultivars. Woody plants such as *Acer palmatum, A. rubrum, Alnus, Betula, Populus, Sorbus,* and certain *Abies, Larix* and *Picea* spp. may decrease in popularity, due to die–back in summer droughts. In contrast, *Acer platanoides, A. pseudoplatanus, Castanea sativa, Pinus nigra* and *P. sylvestris* should hold their own, with more frequent plantings of *Carpinus, Cercis, Cupressus, Ginkgo, Gleditsia, Hippophae, Rhamnus, Robinia* and *Pinus pinea.*

Figure 7.13: *Cotinus coggygria* 'Royal Purple' despite having relatively large leaves is well adapted to drought, through its ability to closely regulate the behaviour of its stomata (the pores on the leaves that allow CO_2 to be absorbed for photosynthesis, and let water vapour out as part of the transpiration process).

Irrigation

In addition to these natural adaptations to drought, cultural techniques may be employed to reduce its impact. The use of stepping stones, rocks, mulch and other surface barriers at the base of plants can reduce soil temperatures and encourage roots to explore cooler, moist 'root runs'. Garden watering, as with current good practice, should focus largely on establishing newly planted specimens. Ideally, planting should take place in autumn when soils are still warm, and moisture levels rise due to the autumnal rains and reduced evaporation from the soil. Planting containerised plants all year round may become more challenging in future and will require thorough watering of the planting hole before and after planting. Subsequently in the period following planting, watering will need to be regular in the absence of rain, with good volumes of water being applied on each occasion. Regular watering (e.g. weekly during summer months) may need to be maintained for 6–12 months depending on species and soil type.

As the garden plant palette alters with climate change, then approaches to management need to evolve too. The traditional approach to summer irrigation, i.e. frequent watering during warm weather, which has become the norm due to the need to meet the demands of bedding plants and the lawn, would be inappropriate for an established Mediterranean plant border. Even without the risk of waterlogging, heavy watering in summer can be detrimental to Mediterranean species, as it activates growth, when the plants would normally enter a quiescent (resting) stage. Plants that would normally abscise leaves to cope with the heat of summer may be induced to form new ones if irrigated, predisposing them to greater water loss should a drier period ensue later on. Other, non–Mediterranean garden shrubs may benefit from similar approaches. Watering strategies during dry weather should aim to keep plants alive, but not to encourage new, soft, succulent shoot growth, that has a high moisture demand, and readily desiccates. Alternating spot watering to either side of a plant may prove useful under these circumstances. This provides a form of "split–root" management, where half the root system is watered (thus re–hydrating the foliage), but the other half remains in dry soil. The roots in the dry soil portion maintain a chemical signal to the shoots that inhibits new growth – this signal is thought to be the plant hormone abscisic acid – ABA, but other root derived chemicals may also have a role (Ren et al. 2007). The signal wears off after a period of 2–3 weeks, but can be re–activated by drying down the portion of roots that had previously been kept moist. In this way, plants seem to be held in 'suspended animation' remaining hydrated, but not actively growing.

During heat waves, the continued supply of mains water will not be guaranteed. Although grey water (waste water from baths, showers, hand basins, kitchen sinks, but not toilets) is increasingly being used directly in arid countries for irrigation, it is unlikely that comparable approaches will be encouraged in the UK without some form of water treatment beforehand. Despite sewage wastewater not being re–used *per se*, grey water can still contain surprisingly high levels of coliform bacteria. It is more likely that interventions such as water treatment with biofilters or encouraging natural bioactivity through circulating grey water through reedbeds, will be required before this source of water will be used widely in the garden. This is less feasible on an individual garden scale, but for domestic private gardens it is more likely that some form of community–based recycling of grey water could be implemented. For heritage gardens, with space to provide a biofiltration plant or a series of small reedbeds, then recycling of waste water from catering facilities, offices etc. could become more practicable.

Possible consequences of a drier climate

One consequence of a warmer and drier climate is that individual flower longevity may decrease, so plants that flower at a single period only may have a curtailed period of bloom. Warmer springs may mean the mass displays of *Magnolia, Malus, Prunus, Rhododendron, Syringa, Tulipa,* etc. are shorter in duration (Fig. 7.14). Species that are continuous or repeat flowering (hybrid–tea, floribunda roses, *Pelargonium* etc.) however, may flower for longer in the season due to warmer weather (assuming water availability remains adequate) and longer growing seasons. The distinctiveness between different seasons and their traditional plantings may diminish. To some extent this can already be seen in that the range of plant species that represent spring bedding is beginning to merge with species that were originally considered summer plantings. *Bellis* and *Primula* can still be on sale in the garden centre, when the first batches of *Antirrhinum, Coreopsis, Lobelia* and *Petunia* arrive. Dry springs, where irrigation is insufficient, will impact on seedling germination, e.g. directly sown flowering annuals and vegetables. Greater resource input (e.g. growing plants on a greenhouse before transplanting, as is currently done with tender, half–hardy annual species) or repeat sowings may be required to ensure food crops become established. Similarly, reduced water availability, or inconsistent watering during later stages may penalise yield. On the positive side, however, warmer periods with good sunlight levels will improve flavour and other aspects of quality, and longer growing seasons may provide more opportunities for multiple cropping of vegetable crops and longer availability of soft fruit such as strawberry and raspberry.

One consequence of less dependable plant performance, is that inanimate features may take greater precedence in the design future, with rocks, stones and ornaments all being used more frequently to provide the *interest* through their texture and structure (Fig. 7.15).

Drier summers have strong implications for weed management in the garden. Weeds significantly reduce a cultivated plant's ability to compete for soil water. Weed control will remain a priority where newly planted specimens are attempting to establish, or where productivity is important – e.g. fruit trees. One advantage of course, is that if weeds are hoed–out during dry periods they desiccate quickly and have less chance of re–rooting. Cultivation also dries out the soil surface, with the soil itself acting as a 'dry mulch' and thus inhibiting weed seed from germinating.

Figure 7.14: Will warmer springs mean that tree and shrub blossom will be more transient?

Figure 7.15: With greater incidence of soil aridity or unpredictable weather events impacting on how some plants perform, there may be a trend for hard landscape features to provide some of the focal points, or create structure within the garden design.

7.4.2 Dealing with wetter winters and increased risk of waterlogging

Some plants are physiologically adapted to wet conditions, this includes the aquatic plants and many of the bog plants gardeners will be familiar with. Some bog plants will not tolerate continual submergence in water, and indeed some drainage in a bog garden is advocated, to maintain a slow movement of water through the soil profile (which tends to bring oxygen with it, whereas completely stagnant water may be much more de–oxygenated). Nevertheless many bog species are adapted to high water tables and temporary periods of inundation. Other garden plants may also survive short periods of waterlogging, but the degree of stress imposed is strongly determined by temperature. Flooding in summer is much more detrimental quite simply because soil oxygen levels become depleted much more rapidly (see points below under resilience). Other biochemical reactions injurious to plant roots occur more rapidly at higher temperatures, for example greater concentrations of the volatile gas ethylene being present around the roots. Ethylene interferes with and damages cell metabolism. Other plants resent over–wet soil/ substrates and these may relate to conditions where classic anaerobism (shortage of oxygen) does not actually occur, but the prevailing wet conditions induce secondary stress factors such as encouraging bacterial pathogens, or alter soil biochemical reactions that affect nutrient uptake or release plant toxins (such as the aforementioned ethylene).

Soil waterlogging in winter tends to be prolonged, not only because there may be greater and more persistent rain, but also because lower temperatures and high relative humidity in the air do not encourage the evaporation of moisture from the soil, effectively there is less 'drying power' than normally occurs in the summer. As mentioned above, plants are relatively well–adapted to short periods of wet soils/ waterlogging in winter but may still succumb if these periods become more prolonged. Overly wet soils have a similar problem to frost bound soils too, in that they are 'difficult to work' and any cultivation tends to damage the soil structure. The pore structure within the soil that lets water and air pass through is compressed and lost by trampling and other compacting forces (especially on clay and silt soils), and cultivation when the soil is very wet leads to the 'crumb structure' of the soil losing its integrity, essentially leaving a more compressed soil with a higher bulk density. It should also be recognised that heavier bursts of precipitation and faster surface flow of rain–water will cause localised soil erosion, and even in gardens with a generally well–structured soil, rills and small gulleys will form that accelerate particle movement leading to some plants without soil at their roots and others with their stem and basal leaves embedded in transported soil.

Where surface puddling becomes a problem from high rainfall, the inclusion of gravel, or organic matter can improve the drainage capacity of the soil, allowing surface water to drain away more freely. On low lying land with a high water table, however, to fully protect plants from waterlogging, raised beds will need to be employed more frequently (Fig. 7.16). These can be either formally constructed using building materials such as brick, sandstone, slate or wooden railway sleepers, or can be informal by contouring the landscape to create higher profile banks and ridges. This can be done using the native soil, or imported aggregates to create scree gardens and gravel banks. Slopes will need to be quite shallow to stop movement of the substrates via gravity, but over time plant roots will help stabilise such structures. Gardeners need to be aware of course that free–draining beds in winter, may become 'droughty plateaus' in summer, and plant choice will need to reflect this.

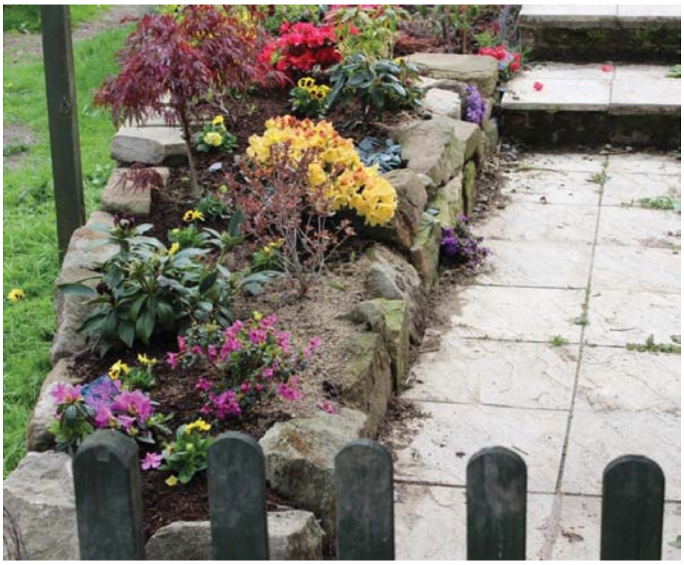

Figure 7.16: A raised bed being used to improve the drainage capacity around plant root systems. Note genotypes such as *Acer palmatum* var. *dissectum* 'Garnet' and *Rhododendron* 'Nancy Evans' require moisture retentive but free–draining soil.

Heavy and more prolonged precipitation patterns will lead to more nutrient leaching from soils, particularly sandy soils with less ability to hold on to key minerals (sand particles have fewer sites that bind chemical molecules such as nitrate or potassium to their surface than those of clay or organic based particles, in essence sands have a lower cation ion exchange capacity). In addition to these soils becoming more nutrient starved over time, they may leach nitrogen and phosphates into surrounding water bodies, causing potential for pollution problems. Nutrient management may become more of a critical issue in the garden, with further moves to encourage bulky organic fertilisers (manure, leaf mould, garden compost) rather than more soluble, readily leached inorganic forms.

7.4.3 Tropical and sub–tropical planting

If regions of the country become frost free, or have minimal frost (e.g. > -5°C) then opportunities for exotic gardening will increase. Exotic gardening can be divided into wet 'sub–tropical' gardens (with lush, luxuriant vegetation) or dry xeriscape gardens (reminiscent of desert landscapes) (Fig. 7.17). The latter will generally tolerate somewhat colder winters, whereas the former will fair best where future summers are moist and warm.

Figure 7.17: Exotic gardens divide into mimics of the warm humid tropics (**Left**) and dry arid tropics (**Right**).

Xeriscape gardens, composed of xerophytic, drought tolerant plants will have much in common with Mediterranean style gardening (See Scenario 2 below), but the species will be even more heat and drought tolerant, with opportunities to mix evergreen sclerophyllous shrubs with succulents and robust grasses. Such gardens tend to rely more on form and design for their aesthetic appeal, as many plants (the ephemeral annual flowering species excepted) have limited flowering period or inconspicuous flowers. Predominant forms will include spires, spikes and low growing mounds and fine–textures, due to small–leaved plants. Species that can be readily utilised include *Acacia, Agave, Allium, Aloe, Artemesia, Cistus, Convolvulus* (e.g. *C. cneorum*), *Cytisus, Echium, Eremurus, Genista, Lavandula, Myrtus, Penstemon* (e.g. *P. pinifolius*), *Perovskia, Phlomis, Phoenix, Punica, Salvia, Yucca* and certain cacti e.g. *Echinocereus, Gymnocalycium* and *Opuntia*. Even within a drier climate, heavy clay soils will need remediation if they are to accommodate xerophytic species, with incorporation of gravel or other free draining substrate to allow sharp drainage when it rains. A more practical approach is to lay a gravel/ sand mix over the parent soil and contour this to provide some variation in level, highly drought–adapted species being placed on the ridges. Where weeds pose a problem, then a permeable membrane can be laid between the parent soil and gravel/ sand mix. Once established, xeriscape gardens tend to be fairly low maintenance, with tasks limited to cutting back dead flower heads and annual trimming of the more vigorous prostrate plants. The dry soil should in general, inhibit weed germination. Not only are xeriscape gardens low demanding in terms of water, but they also require little feeding, most plants being adapted to nutrient poor soils. For the drier regions of the country, xeriscaping will be appealing due to the reduced demands on domestic water supplies.

Semi–tropical gardens may become more common in those regions that experience an increase in both temperature and rainfall (See Scenario 1 below). These conditions, in the absence of any significant frost, will promote the popularity of strong–growing and large–leaved plant species reminiscent of the tropics. *Brugmansia, Canna, Cordyline, Hedychium, Hemerocallis, Musa, Perilla, Phormium, Solenostemon, Xanthosoma* as well as various bamboos being used to good effect. Increasing rainfall may need to be tackled by more sophisticated drainage schemes with surface water being encouraged to flow to areas where it can be trapped and managed more successfully (i.e. avoiding flood damage to the major infrastructures – house, out buildings etc.). Gardens on slopes may become terraced to help avoid soil erosion during extreme rain storms and reduce the risk of top–soil being translocated down–hill. Ponds and rain–gardens are likely to become more common as gardeners adopt features that are more conducive to the climate.

Public reaction to non–native/exotic climate–adapted planting

In other parts of the world, e.g. the southern states of the USA and Australia, there has been resistance to move away from westernised landscape styles and adopt better climate–adapted gardens (Martin 2008; Chui 2014; Garcia et al. 2014). Much of the drive to change garden style has come from state or local authorities worried about unsustainable use of water in arid/ semi–arid regions or that such western landscape styles alter the natural ecosystems, for example by not providing the native plants that the indigenous wildlife depends on. As such, xerophytic and exotic plant designs, although advocated, may not always find favour with residents who aspire to verdant lawns and herbaceous borders, even when living in Arizona! This has led to the consideration about how the UK public would view landscapes that are more orientated towards a warmer climate.

Hoyle (2015) studied people's responses to garden/ park style to test their acceptance of landscapes that reflected more exotic or drought/ heat adapted styles, and whether they welcome the greater use of non–native plants in particular. Questionnaires were conducted on over 1400 people, who had walked through parks and gardens of varying and contrasting styles. This included styles that largely reflected a spectrum from traditional UK landscapes (e.g. broadleaf woodland largely composed of native species) through to Mediterranean style gardens containing xerophytic species. Results indicated that in principle the majority of people would be happy to see more non–native plant species in UK parks and gardens. A minority of participants, however, thought that planting should be restricted to native UK species. Factors driving acceptance and rejection of non–native plants included the overall aesthetics, awareness about climate change and implications for garden/ park flora, knowledge about the historic tradition of importing plant species from elsewhere, concerns about the potential invasiveness of non–native plants, worries about their incompatibility with UK invertebrates as well as the scale and locational context of the planting (acceptable in some places, but perhaps not in others). Some people expressed a clear awareness that plant species had been imported to the UK from all over the world for hundreds of years, and that the use of 'non–natives' in UK planting was not a new phenomenon.

Interestingly, on the whole, non–natives/exotics were considered more attractive than indigenous native plant species, yet reactions were very species specific. In the case of woodland planting people seemed to appreciate particular forms such as the curving branches of *Eucalyptus* trees (Fig. 7.18), and the lush 'subtropical' multi–layered woodland at Abbotsbury, Dorset. Mediterranean planting including *Cordyline australis* and other xerophytic 'spiky' forms produced mixed reactions with some people associating these positively with holidays in warmer climates, and others perceiving them as hostile and aggressive. When participants were informed that Mediterranean plantings might be better adapted to the future climate than those species used in urban planting at the present day, positive reactions to non–native planting increased.

Figure 7.18: Respondents expressed a liking for the form and structure of *Eucalyptus* stems and branches, despite it not being typical of current UK landscapes.

Many people expressed reservations about the wider use of non–native/ exotic species in UK parks and gardens, even those who were generally positive about their introduction. The main concern was the perceived invasiveness of non–natives, although some acknowledged that with increasing knowledge and monitoring this might be overcome. There was also the concern that non–native plants would not be compatible with native invertebrates. Participants also demonstrated concern about the scale and context of non–native planting. This was sometimes related to worries about invasiveness, with the fear that non–native planting might 'take over' native biodiversity. Some participants demonstrated a well–developed sense of context, for example the opinion that areas in the south of England or on the coast were considered suitable locations for 'non–native, English–riviera' style planting, but that it would be incongruous in a more northerly city such as Sheffield. There was some suggestion that this might be related to familiarity, in that those participants more regularly exposed to Mediterranean planting were more comfortable with and positive about its introduction (Hoyle 2015).

Even for existing landscapes, responses could vary with time of year or context. Interviews with some participants who had walked through areas of shrub planting suggested that positive responses to *Rhododendron* planting were related to the percentage of flower cover present; more positive when in flower, less so when out of flower.

7.4.4 Resilient Planting

The UKCP09 climate change scenarios point not only to a steady increase in temperature and a steady decrease in summer rainfall but also to an increase in the frequency of extreme weather events, both droughts and periods of intense precipitation. Gardens in low–lying areas may be inundated with floodwater on a more frequent basis, either from heavy rainstorms, or tidal surges (Fig. 7.19). This will present the greatest challenge for gardeners, and potentially the one that holds the least opportunity for the use of new plants. It may also be a situation for which gardeners need to modify their landscapes the most, as they attempt to maintain a diverse range 'garden habitats' (See Scenario 3 below). Dry areas of the garden may end up being flooded on occasions, and conversely wet localities experiencing soil moisture deficits at other times. More volatile weather patterns will also pose a challenge for the typical structures and features integral to the traditional UK garden. Glasshouses, fences, trellis and sheds will have to deal with stronger winds. Trees in full leaf may be wind–blasted, with increased risk of wind throw if strong winds also become unseasonal. There may be a trend for smaller or fastigiate trees, or those such as sycamore *(Acer pseudoplatanus)* and hawthorn *(Crateagus monogyna)* that have a reputation for resisting wind damage (Fig. 7.20). Interestingly, certain *Magnolia* proved to be among the most resilient trees when gardens in the southwest were subject to the gales of 1987, so the choice of wind–resistant species need not be confined to less attractive species. In contrast, the large–leaved, evergreen *Rhododendron* species and cultivars are prone to wind rocking. Wind damage will open up tree canopies and woodland species that prefer a degree of shelter may find themselves in full sunlight or exposed to the full blast of the prevailing winds.

Gardens may take on the appearance of municipal landscapes as the tough, robust shrubs and perennials associated with these tend to be those that prove most reliable under a range of diverse stress conditions. This includes *Buddleja davidii, Convallaria majalis, Cotoneaster horizontalis, Euonymus fortunei, Helleborus niger, Prunus laurocerasus, P. lusitanica, Ribes nigrum, Rosa glauca, R. rugosa, Sedum spectabile* and *Vinca major*. Compact, low growing species including those within more naturally wind tolerant groups (e.g. the grasses) may be in favour on more exposed sites, with walls, pergolas and courtyards used to protect fruit, vegetables or larger flowering ornamentals.

Figure 7.19. Garden plants will need to tolerate wetter soils in winter, and those within river or coastal plains the occasional flooding event.

Figure 7.20: *Acer pseudoplatanus* (**Left**) and some forms of *Pinus nigra* (**Mid–right**) tolerate exposed windy sites.

Less resilient plants may be grown in pots and containers and moved to more sheltered locations when extreme weather is predicted. There may also be a trend for growing true species rather than derived cultivated forms, on the assumption that the true species possess more genes promoting stress tolerance and have greater capacity to store carbohydrates thus ensuring longer term survival. Resilient 'ruderal' plant species such as *Taraxacum officinale* (dandelion) are often successful due to their ability to capture resources and store them in a tap root or other organ. In contrast, hybridised plants are often selected on the basis of those that allocate significant resources to flowering (number, longevity, repeat flowering habit) or other ornamental features. However, exploiting 'hybrid vigour' may also have a role in improving plant performance, as crossing two species could be used to improve resilience rather than exclusively to promote aesthetic features.

Research commissioned by the RHS investigating how hybridisation has affected resilience in *Primula* and *Viola*, has tended to suggest that in these two plant genera at least, hybridisation that results in very flamboyant flower traits may reduce the plants resilience (Lewis, personal communication). So for example, the native primrose, *Primula vulgaris* is able to tolerate heavy soil wetting and excessive drying (and indeed, oscillations between these two extremes) more effectively than the highly bred *P.* 'Forza'. Interestingly the cultivar *P.* 'Cottage Cream' that is superficially quite similar to the species, also had greater resilience than *P.* 'Forza'. This may suggest stress tolerance is partially being sacrificed for more floriferous genotypes with larger flower sizes (Fig. 7.21). This needs to be confirmed by further studies, across a much greater range of species however.

Figure 7.21: The native primrose *Primula vulgaris* shows more resilience to flooding (as seen here) and drying cycles that some of its derived cultivated forms.

If the future brings greater oscillations in wetting/ drying periods, then horticulturists may look to the wild for those species that have adapted to similar scenarios, i.e. whose eco–physiology allows a degree of tolerance to both soil waterlogging and soil drying, for example species that are found along dry river beds, where both the ability to survive a drying soil and a 'receding water table' is combined with tolerance of temporary water inundation when the rivers are in spate. One such species, the red–river gum *(Eucalyptus camaldulensis)* – a riparian (river–side) tree of Australia shows greater adaptability to both drought and waterlogging compared to more typical dry woodland species such as *E. globulus* (Gomes and Kozlowski. 1980). Further research is required to identify garden–worthy plants that tolerate both a high degree of soil wetting and soil drying at different times of the year. However, surveys by the Royal Horticultural Society where they asked garden professionals about their experiences of plants that seem to tolerate both winter wet and summer drought demonstrated an interesting range of species and cultivars. A full list of species can be found on the RHS website (RHS, 2015).

Surprisingly high numbers of plant genotypes can tolerate a limited period of waterlogging in the winter, due to reduced respiration rates in the roots at low temperature. As soils warm though, the amount of oxygen that is held in solution decreases, just at the point when actively growing root cells need it most. As such, growth and survival rates decrease between winter and summer even when plants experience the same duration of waterlogging. Studies by King et al. (2012) on Mediterranean plant species showed that fatalities only occurred in prolonged flooding during spring or summer and only with some species. Survival rates being *Lavandula* = 100% throughout; *Stachys* = 100% throughout; *Cistus* = 100% survival in winter and spring, 67% survival in summer and *Salvia* 100% survival in winter but 70% survival in spring and 60% survival in summer. Growth was also penalised during warmer periods, even in those plants that survived the waterlogging (Fig. 7.22).

Figure 7.22: Biomass production (growth) in *Salvia officinalis*, *Lavandula angustifolia*, *Stachys byzantina*, and *Cistus* x *hybridus* after flooding during winter (Win.), Spring (Spr.) or Summer (Sum.) for either Short (3 day) or Prolonged (17 day) floods. Data presented as percentage of control values for each season (King et al. 2012).

7.5 Ideas for garden design in a changing climate

Adaptive strategies that may be exploited in domestic gardens to counter the challenges outlined above have been succinctly summarised in a series of design schemes. Note scenarios relate to a future date of *2100* (and assume certain trajectories – so called Representative Concentration Pathways – RCPs). These scenarios are not designed to *predict* the future, but rather attempt to *demonstrate the trends* in garden style that may occur as the climate progressively changes towards the end of the century. The designs and recommended plant species can be scaled up or down depending on garden size. Elements of the designs and plant suggestions should also be useful for balconies and container gardens.

7.5.1 Design Scheme 1

West Country Gardens – By 2100, mean temperature 3°C warmer than current. Heavy winter precipitation and moderate summer precipitation – storms more frequent and prevalent westerly winds. A frost–free climate with mild, high humidity winters. Periodic, but variable periods of warm dry weather in summer. Growing season longer.

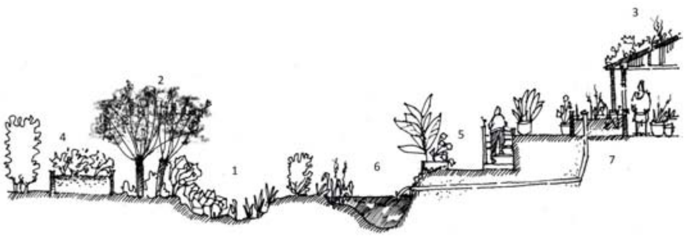

Figure 7.23: Design scheme 1 – Numbers on diagram refer to points in text below.

Garden Features

- Many lawns have been converted into woodland or shrub borders, due to the demands of mowing all year round, and where the frequently wet turf is not conducive to cutting.
- More ditches, rills, swales, pond and rain–gardens are introduced – this provides greater accommodation of wetland plant species (1).
- Large trees on wet soils are more prone to wind–toppling so there is a transition to smaller species, or larger species are coppiced/ pollarded to reduce crown weight (2).
- Some loss of patios and other sun spots, especially in winter.
- Slippery paths are more of a problem and wooden features have reduced longevity due to higher humidity.
- Green roofs are widely adopted to minimise run–off rates from built structures. Roofs accommodate a range of wet montane plant species, not just drought adapted ones (3).
- Gravel raised beds are used above heavy soils to allow traditional favourite garden plants to grow in the wetter climate, e.g. *Allium, Aster, Dianthus, Geranium, Pelargonium* and *Tulipa* (4).
- Gardens on slopes are frequently terraced to stop soil erosion (5).
- Fashion develops for ‘natural’ water features, such as ponds and streams. Adoption is encouraged by legislation to reduce the rate of run–off water from land after heavy precipitation.
- Gutters and downpipes feed into planted storm water retainers. White cloud minnow and other semi–tropical fish are used to control mosquito larvae in standing water features (7).

Plantings

- Greater pathogen pressure. Many existing tree and shrub species prone to more fungal and bacteria pathogens, e.g. *Phythopthora* and *Pythium* spp.
- Lichens and moss are a more common and distinctive feature on garden plants.
- *Camellia, Escallonia, Fuchsia* and other ‘temperate’ species become dominant hedge and boundary plants.
- Groves of *Acacia, Embothrium, Eucalyptus* and similarly – adapted species have become commonplace where gardens and other landscapes provide sufficient space and shelter from the wind.
- Shelter belts are used to protect large–leaved, semi–tropical species from wind tear. This includes *Brugmansia* (angel’s trumpet) *Canna, Colocasia esculenta, Hedychium* (gingers), *Musa basjoo* (Japanese banana), but also *Ensete ventricosum* ‘Maurelii’ – the purple Abyssinian banana.
- Pot–grown *Monstera delicosa* are moved indoors in winter to protect them from storm damage.
- *Crocosmia* spp. are now considered a landscape weed.
- Apart from the most disease resistant rose cultivars, many cultivars of rose have disappeared due to black spot disease *(Diplocarpon rosae)*.
- Dessert apples have given way to juicing and cider varieties.
- Ornamental cherries *(Prunus)* and crab apples *(Malus)* have lost some of their popularity due to wind damage to blossom and bacterial/ fungal pathogens.

7.5.2 Design Scheme 2

East Anglian Gardens. By 2100 mean temperature is 5°C warmer than current. Moderate winter precipitation with limited summer precipitation – soil moisture deficits common in summer. Frost uncommon and rarely below -4°C. Growing season longer.

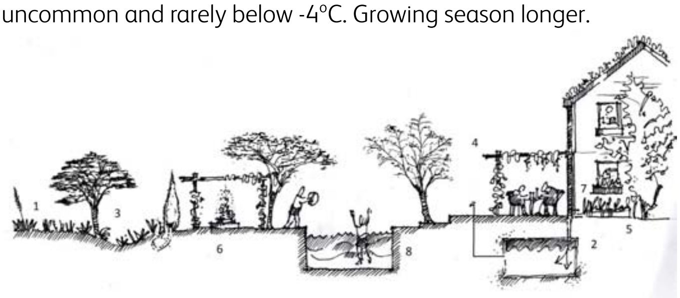

Figure 7.24: Design scheme 2 – Numbers on diagram refer to points in text below.

Garden Features

- Some lawns have been converted to dry steppe meadows, with bulb species being used to extend the flowering period. Dry grasses and other stems and seed heads are used to provide form during mid–late summer after the peak flowering period. Spot plants include *Agave americana, Eremurus* and *Echium* spp (1).
- Grass lawns have been replaced in some gardens by artificial synthetic lawns in an attempt to replicate the verdant

appearance of the traditional lawn. This is beginning to be commonplace for families with children where open playable space remains desirable but where the ability to maintain a real grass lawn is becoming too challenging, due to a lack of consistent rain in summer. Biopolymers (e.g. from starch) are now used to manufacture the synthetic lawns, thus reducing the reliance on oil–based polymers, but these second generation artificial lawns are still not an ideal habitat for wildlife.

- In other gardens the lawn has also disappeared, to be replaced by gravel beds and hardy 'cornfield' annuals; the latter providing peak flowering in May – June.
- Down pipes from the house roof are connected to an underground tank to store rain water run–off that can be used in the garden during summer (2).
- Trees are planted with a perforated watering pipe penetrating into the rootball to provide deep watering during hot periods. Although this may encourage localised rooting around the pipe, the benefits outweigh the disadvantages.
- Plants bought from the garden centre and nursery will be preconditioned to drought stress during the production phase (but brought back up to full water status before shipping to the sales bench). Drying–down the nursery plants in a controlled way preconditions plants to subsequent drought phases and aids survival after planting in the garden; the establishment phases being the most vulnerable time for many ornamental plants.
- Gardens are screened to the south and west to provide mid–day shade. Species such as *Citrus*, *Cercis siliquastrum* (Judas tree), *Prunus dulcis* (almond), *P. persica* (peach) and *Olea europaea* (olive) are commonly used. In some gardens these are located in shallow scrapes of which recycled grey water from the Local Authority communal tank is added when required (3).
- Patios are used more frequently, and have become important hubs for the social activities of the household. Shade is provided by species such as *Catalpa*, *Koelreuteria* and *Paulownia* where moisture availability allows (4).
- Wall climbers are planted around the air conditioning units of houses to improve their cooling efficiency further. A mixed collection of *Bougainvillea*, *Ipomea learii*, *Jasminum* and *Wisteria* provide both shade and evapo–transpirational cooling to the unit. These are again linked to irrigation systems using recycled water to ensure plants remain adequately watered during heat waves and continue to provide a cooling service to the house (5).
- Shallow swales and depressions are used to recreate 'dry' riverbed landscapes, with prominent use of gravel, stones and 'drift' wood. Planting is infrequent, but used to good effect to promote form (e.g. grasses such as *Miscanthus sinensis*) and brief interludes of colour via flowers (e.g. *Eschscholzia caespitosa*).
- Although water will be a challenging feature to manage due to high evaporation rates, rills, small pools, bubble fountains etc. become increasingly important to provide relief from the heat and dryness experienced in summer. Windbreaks and sheltering walls help ensure these areas minimise wind movement and hence reduce the amount of moisture lost as spray, or evaporated from the water feature (6).
- Colourful patio plantings and window boxes are located close to the house to help ease of watering. Plants currently semi–tender become main–stream. *Bidens* for example, flowers from June to December (7).
- Borders and beds are more frequently mulched to reduce soil temperatures and inhibit evaporation of moisture from the soil. Mulch will include organic materials e.g. pine bark, but also inorganic materials such as pebbles, crushed glass etc.
- Shade becomes a more important element in the garden to help mitigate effects due to dry soil (although there will be less cloud cover – solar irradiance itself won't increase). Nevertheless, drought sensitive species will be given some respite by providing shade/ semi–shade especially during the middle of the day.
- More gardens accommodate a swimming pool to capitalise on the warmer summers now prevalent (8).

Plantings

- Higher temperatures increase the range of plants that can be grown, although this is somewhat confounded by greater incidence of soil moisture deficit in summer. Evergreen sclerophyllous species (e.g. *Arbutus* spp., *Eucalyptus* spp. *Garrya elliptica, Laurus nobilis* and *Quercus ilex*) and smaller or pinnate leaved–species *(Acacia dealbata, Albizzia julibrissin, Argyrocytisus battandieri* and *Tamarix spp.)* as well as drought tolerant pines (e.g. *Pinus aleppo, P. halepensis, P. pinaster* and *P. pinea*) and palms (e.g. *Phoenix canariensis* and *Trachycarpus fortunei)* become more common.
- Summer soil moisture deficits mean that conventional garden shrubs such as *Cotinus, Cotoneaster, Photinia* and *Syringa* have shorter internodes, and tend to be smaller and more compact plants than is currently the case. Even climbers such as *Clematis, Wisteria* and grape vines *(Vitis)* are less vigorous and have reduced shoot extension. This compaction, however, results in a more intense flower display, as the flowering nodes are not spaced so far apart.
- The drier climate not only reduces growth of plants, but increases the longevity of species adapted to such climates, such as Mediterranean shrubs/ sub–shrubs *(Ceanothus, Fremontodendron, Lavandula, Rosmarinus* and *Salvia* spp.) as growth is more in line with quiescent/ dormancy phases, and there is less pathogen pressure brought on by damp weather.
- On light soils, mixed borders have lost their hybrid–tea roses in favour of species roses and drought tolerant climbers such

as Rosa ‘Veilchenblau’, ‘Alberic Barbier’ and ‘American Pillar’. Border dahlias have been replaced by *Osteospermum*. Grey and evergreen foliage becomes more prominent in mixed borders as greater reliance falls on Mediterranean shrubs and sub–shrubs.

- Herbaceous perennial borders still occur, but the range of species tends to omit those that require good levels of moisture such as *Aconitum*, *Astilbe*, *Dicentra*, *Dodecatheon*, *Filipendula*, *Galega*, *Heuchera*, *Hosta*, *Primula*, *Pulmonaria* and *Trollius*.
- Species such as *Ceratostigma plumbaginoides*, *Hypericum olympicum*, *Rosmarinus officinalis* ‘Corsican Blue’, *Stachys byzantina* and *Vinca major* remain reliable ground coverers, but others such as *Ajuga*, *Bergenia*, *Polygonatum* and dwarf bamboos become less common.
- Rock gardens have lost many of their European and Asian alpine species, but now host xerophytes from Australia, North America and South Africa.

7.5.3 Design Scheme 3

North England Garden By 2100, temperatures 2°C warmer than current, winter mean rainfall has increased, summer mean rainfall similar to current. More extreme weather events, with moderate risk of significant frost due to a weakened gulf stream, greater frequency of heavy precipitation events and storm surges and more frequent occurrence of summer, soil moisture deficits and heat waves. Oscillations and rapid transitions between different weather events become more common.

Figure 7.25: Design scheme 3 – Numbers on diagram refer to points in text below.

Garden Features

- Garden features in general similar to current. Gardeners still desire open areas of lawn, tree and shrub cover and interest provided by flower beds and borders.
- Gardeners are more challenged in the choice of species and cultivars that will cope with the potential extremes in temperature (-15°C in winter to +40°C in summer), wetness and dryness as well as more rapid oscillations and cycling of different weather events (e.g. drought followed by flood).
- Some garden features are designed to deal with extremes of climate – for example raised beds with free–draining soil are now provided with a network of seep irrigation hose to provide water during warm dry periods (1).
- Due to the potential of heavy precipitation, gardens are designed to cope with rapid run–off, with drains and catchment areas used to divert water away from built structures and to use vegetation to slow the rate of water released into the drainage system (2).
- Flood and storm–water surges will leave deposits of silt (and potentially salt) on the soil and on plant foliage. Paradoxically, once flood waters ebb away, the garden may need to be flushed with fresh water to remove or dilute these deposits.
- Gardening under protection or semi–protection becomes more in vogue, although this is tempered by greater risk of structural damage to features such as glasshouses, polythene tunnels and conservatories. Less robust species may be located next to walls and shelter belts, under pergolas or by the house where the physical structures give a degree of protection against frost and strong winds (3).
- Fruit and vegetables are grown by walls, raised beds and along sheltered paths, alleyways and courtyards (4).
- More plants are grown in containers to allow movement between protected and less protected areas. For example some species are moved into glasshouses in winter, patio in spring for peak flowering display, and then under a shady arbour in mid–summer (5).

Plantings

- Plants that dominate the garden landscape are ones with a high degree of resilience to stress in general, and have a natural range that covers a wide geographical or habitat range. Garden stalwarts such as *Amelanchier*, *Berberis*, *Buddleia*, *Cotinus*, *Forsythia*, *Hypericum*, *Lavatera*, *Magnolia stellata*, *Philadelphus*, *Potentilla*, *Ribes*, *Sambucus*, *Spirea*, *Viburnum tinus* and *V. opulus*, as well as climbers such as *Clematis montana*, *Hedera*, *Lonicera*, *Parthenocissus* and *Solanum crispum* are strongly relied upon.
- Garden trees and those used in the wider landscape tend to be robust species, with good levels of cold and heat tolerance (e.g. *Abies*, *Acer pseudoplatanus*, *A. platanoides*, *Cedrus atlantica*, *Laburnum*, *Picea*, *Pinus sylvestris*, *P nigra*, *P mugo* and cvs, *Platanus × acerifolia*, *Robinia* (where protected from the wind) and *Tilia*.
- Resilient herbaceous plants include *Aquilegia*, *Aruncus*, *Aster*, *Eupatorium*, *Euphorbia*, *Filipendula*, *Geranium*, *Helleborus*, *Hemerocallis*, *Hesperis*, *Leucanthemum*, *Lychnis*, *Papaver*, *Persicaria*, *Salvia*, *Solidago* and *Stachys*.
- Due to the increased variability in climate, there may be a trend towards short–term plantings, so annual plants and short–lived patio plants remain popular, despite their relatively intensive management requirements (annual planting, or sowing, irrigation and nutrition). Therefore, *Antirrhinum*, *Bellis*, *Calendula* and *Viola* (pansy and viola) retain their popularity.

7.6 Conclusions

Climate models predict that our climate will become increasingly variable through time and space, and a certain degree of warming is now inevitable as a consequence of previous greenhouse gas emissions. Gardens have an important role in helping to mitigate against the effects of climate change, as certain management practices may help to reduce greenhouse gas emissions, or help fix (sequester) atmospheric carbon into the soil. Indeed, this marks an important area for future research.

Increasing housing pressures will run in tandem with the need for local authorities to take action against the implications of climate change such as flood prevention, therefore gardens are likely to become increasingly important in legislative processes – more broadly in society as a component of Sustainable Urban Drainage Systems, but also as part of the transition to a more sustainable way of life for the individual.

Whilst this chapter has looked to the future in relation to role of gardens in helping to mitigate against climate change, what gardeners are experiencing now and ways in which garden design and planting schemes can be adapted are also presented. Suggestions here will help gardeners to 'future proof' their garden, however, effective management practices for climate mitigation remains largely unknown and – owing to the large proportion of urban green space accounted for by gardens – it is likely that their role in offsetting climate change is currently largely underestimated.

8. Conclusions

This report combines the results of a survey with a wide range of published literature in order to establish the consequences of climate change for gardening and horticulture. The 2002 'Gardening in the Global Greenhouse' report highlighted ways in which garden management could be modified under predictions for climate change available at the time. The current report builds on this firm grounding by providing empirical evidence which suggests that both amateur and professional gardeners have noticed the effects of climate change and are already adapting management practices accordingly.

8.1 Developments since the 2002 report

Since the 2002 report, greenhouse gas emissions have followed the trajectory of the highest emissions scenario. In addition, there is a higher degree of certainty in model projections and there is a greater understanding of how greenhouse gas emissions will result in increased climate variability for some parts of the world. Average temperature in the UK tends to change in–line with the global average, and signatory countries of The Paris Agreement have recently committed to ensuring this figure remains below 2°C – although our current trajectory would result in global average temperature rising by 4°C. Whilst such an increase in temperature might seem marginal, it is the repercussions, such as glacial melt and the alteration of atmospheric and ocean circulation, that is of concern. For example, the UK is generally likely to experience hotter, drier summers and milder, wetter winters as a result of rising global temperatures. However, in both seasons, rainfall in particular will become increasingly variable. There will also be regional variation, as the difference in temperature and rainfall between the north and south of the UK will become more extreme.

In 2012, Defra released the first Climate Change Risk Assessment report, which was reviewed in 2017. The most recent report identified invasive organisms (including pests, diseases and invasive non–native species), resource use and soil health as key risks of climate change and highlighted the need for further research in these areas (Defra 2017). These risks align with those found by this report to be particularly relevant to gardeners, and are therefore fundamental in underpinning scientific research at the RHS.

8.2 Synthesis

It is apparent from the results of the survey that gardeners are already experiencing climate change, with the establishment of new pests and diseases reported as a primary concern. A review of the interactions between the garden and the natural environment in Chapter 5 reiterated that the transport of plants for horticulture is the primary pathway for the introduction of new pests and diseases, and that the success of introduced species tends to rely primarily on the geographic distribution and health of their host species. There is, however, preliminary evidence to suggest that climate change might be a contributing factor to the success of some pests and diseases, such as the oak processionary moth and *Heuchera* associated powdery mildew.

One opportunity noted by survey respondents was the possibility of growing exotic frost–tender species and, as a result of climate change, it is increasingly likely that exotic species will be able to survive in the natural environment. As highlighted in Chapter 5, growing exotics is a source of potentially invasive species if gardeners do not follow the correct disposal procedure. For example, hottentot–fig is a drought tolerant plant native to South Africa that has gained popularity as a drought tolerant ground cover plant with bright pink or yellow flowers. In the UK, this species is highly invasive on southern and western coastal cliffs but its expansion is limited by our winter frosts. However, milder seasons could lead to a steady northerly spread and the more frequent occurrence of summer droughts could allow the species to establish inland. The spread of invasive species, such as hottentot–fig, often results in the loss of native flora, thus disrupting existing ecosystem processes.

The survey indicated that people are mowing their lawns more frequently in the spring and autumn, suggesting that an extension to the growing season has been noticed by the gardening public. As discussed in Chapter 6, the number of growing degree days has been increasing in the last decade throughout the UK, but southern regions still experience a longer growing season than northern regions. Chapter 6 also presented empirical evidence to support the significant influence of temperature on the flowering time of some species, as a large proportion of respondents reported noticing earlier flowering. A similar number also noticed later flowering, and this is probably due to a lack of chill period (for those species that require it) as a result of milder winters. The ability to predict flowering time based on temperature has an important ecological application, as possible mismatches between plants and their pollinator, for example, could be anticipated.

It is possible that soil health will decline, due in part to mild winters punctuated by waterlogging, interspersed with sporadically dry soils and rising soil temperatures. However, there will also be many opportunities, such as a longer growing season, the opportunity to grow a wider variety of plants and an increase in the use of the garden as an outside space. Chapter 7 gave examples of how to design a 'future proof' garden depending on location, how to maintain good soil health, and suggested species that gardeners can plant now in order to buffer some of the possible implications of climate change. A key opportunity for both gardeners and society more widely is the role of gardens in climate change mitigation, something that could be achieved through management strategies which reduce greenhouse gas emissions and enhance carbon storage. Despite the large proportion of green space accounted for by gardens in the UK, this particular function has been overlooked and thus specific management practices to achieve this remain largely unknown.

The following section outlines the implications of climate change for horticulture, ways in which gardeners can act now and also suggests what can be done nationally.

8.3 Implications for Gardeners

1. Warmer springs and autumns will extend the growing season and, therefore, some species will flower earlier and some will experience delayed leaf colouring or leaf fall. The growing season was around 10 % longer in 2015 compared to the 1981 to 2010 baseline, and analysis of flowering times indicate that the growing season will continue to increase with rising temperatures. There will also be the need for more pruning, mowing and weeding.
2. A longer growing season might allow for a wider variety of plant species to be grown, especially tender ornamentals and edible plants. Although, when attempting to grow different varieties, gardeners will face a continual trade–off between a longer growing season and the implications of extreme weather events, such as heavy rainfall damaging plant tissue.
3. The amount of solar radiation available to the plant for growth has increased by around 5 % relative to 1961–1990. This has been linked to a reduction in cloud cover.
4. Extreme rainfall events might increase the rate that nutrients, particularly nitrogen are washed out of the soil. Therefore, the timing of fertiliser application should be carefully considered. When combined with heat stress in some areas, this could result in a reduction in plant growth. The leaching of nitrogen into public waterways may result in environmental problems such as algal blooms.
5. Dry spells are projected to increase, and gardeners will need to consider methods of capturing water during intense rainfall events and storing it so that supplies can last for several months over the summer. Dry spells and rising temperatures will also increase the need for irrigation.
6. It is expected that warmer conditions will favour the spread of existing pests and diseases, in addition to the establishment of new cases. Warmer conditions will be compounded by dampness and humidity following heavy rainfall, resulting in ideal conditions for the establishment of a variety of pests and diseases. Environmental conditions might result in stressful growing conditions for the plant, making them more vulnerable to attack. However, climate change will mean that populations of those pests and diseases who exploit frost wounds, for example, may struggle to survive.
7. Even if greenhouse gas emissions are reduced today, the climate will continue to change rapidly over the coming decades due to historic emissions, but change will eventually begin to slow. Consequently, gardeners should be mindful that trees planted now might not be suited to the climate in 2050, for example. In addition, increased climate variability on a season by season basis will mean that gardeners should think on much shorter timescales for tender ornamentals, as what grew successfully in one year might not do so well in the next.

8.4 What can gardeners do?

1. **Green your living space.** Wherever possible, plant a large tree or shrub and green up any bare patches. Trees and plants remove heat–trapping CO_2 from the atmosphere, reduce the risk of flooding, and some species can even capture particulate pollution.
2. **Plant a diverse range of plants in your garden.** Earlier flowering might disrupt host–pollinator associations, so plant a diverse variety of pollinator friendly plants with different flowering times. Use the RHS Perfect for Pollinators list to increase the number of pollen and nectar sources at different times of the year.
3. **Adopt new ways of growing.** Green roofs and walls can result in year–round home energy savings due to a cooling effect in summer and an insulating effect in winter. Improve energy efficiency through use of new technologies and growing systems such as self–watering containers, solar powered garden products and smart phone devices linked to automatic monitors, sensors, LED light timers and irrigation systems. Also try to reduce the use of petrol–powered tools.
4. **Water use and management in gardens.** Improve water capture and storage infrastructures with a larger capacity than standard water butts to ensure a sufficient water supply over the summer. Select plants better suited to the environment, or incorporate appropriate garden design strategies like rain–gardens and Sustainable Urban Drainage Systems (SUDS).
5. **Avoid peat.** Peatlands store considerable amounts of carbon. Look, ask for and use peat–free composts. There are now some high quality products out there that work.
6. **Compost your garden and kitchen waste.** Gardeners may wish to compost more garden and kitchen waste as this provides excellent nutrients for the garden, but thrown away as household waste, it ends up on landfill and produces potent greenhouse gases.
7. **Adopt the 4R's. Reduce** – the use of resources in your garden wherever possible; **Reuse** – household materials and seasonal items year on yea**r Recycle** – your garden waste, plastic, glass and metals and **Reinvest** – help stimulate demand for recycled products by buying recycled items.
8. **Avoid wherever possible the use of chemicals in your garden.** As a first choice avoid the use of chemicals in the garden. If required, use products with a low carbon footprint.

9. **Practice Integrated pest Management (IPM)** Adopt a combination of good plant biosecurity, monitoring, biological, cultural and chemical controls in order to minimise the spread of pests and diseases.
10. **Invasive Species.** Gardeners can help to reduce the possible expansion of invasive species in the wider environment, by ensuring that their cultivated plants remain in the garden, and that legislation is adhered to during plant disposal.

8.5 What can be done at a national level?

Increasing housing pressures will exacerbate the possible implications of climate change outlined in this report. As a result, gardens will become increasingly important over the coming years, especially for flood protection, local climate buffering and the provision of green space for wildlife. Gardening at a community scale will minimise the impact of some elements of climate change, such as the implementation of Sustainable Urban Drainage Systems for flood alleviation. We are also discovering that the functional traits of some plants, such as their ability to cool the surrounding environment, may reduce the requirement for the artificial maintenance of microclimates (such as air–conditioning systems). Some species can even trap pollution more effectively than others so that air quality can be improved. All of these functions are in addition to the important contribution of gardens to our health and well–being, and adds weight to the argument against a growing trend for 'garden grabbing'. Consequently, policy makers at both a national and local level should prioritise the importance of maintaining green spaces and private gardens in new housing developments.

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