Conclusions

Climate change is not something about to happen. It is something which is already here and is accelerating at a rate not previously experienced in the Earth's recent history. Current concerns about the potential effects of climate change on gardens have arisen not out of a theoretical possibility of change, but because we are already facing the consequences of climate change and extreme weather events.

The great storm of October 1987 marked a watershed in thinking about trees and gardens, with the realisation that nothing is immortal. Plant populations in gardens require constant management, development and renewal if they are to survive. The timespan within which major decisions need to be taken in gardens, will result in climate change becoming a significant factor in determining the direction and objectives of management inputs. With the exception of historically important gardens with closely prescribed planting schemes, gardens will be able to adapt to climate change and some will benefit, but the cost of adaptation may be considerable.

In discussing the impacts of climate change on UK gardens, it is important to distinguish between long term trends and the occurrence of sudden extreme events. The two main trends are steady increases in mean temperature and a reduction in annual precipitation, particularly in the summer, but the scale of change varies by region across the UK. The combination of heat and drought will be most damaging to large trees growing on light soils in the south of England, but its effects will be felt to a greater or lesser extent throughout the UK. In the north, for example, more rapid growth of vigorous annual weeds will threaten gardens where slow growing plants are particularly susceptible to competition, and gardens on steep slopes with shallow rocky soils will be very susceptible to drought.

The more dramatic impacts on gardens come from extreme weather events, particularly droughts, gales and floods. These are unusual and unpredictable events but they help to emphasise the importance of sustained management of the garden heritage, of not allowing a garden to slip into senile decay, in which condition it is vulnerable to even a modest gale.

The symbol of a garden as Paradise, a Garden of Eden, is an ancient but still a powerful one. The image of the UK as one large garden, a green and pleasant land, is a source of pride, pleasure and healthy exercise for many of its inhabitants and a magnet for tourists. Our garden heritage is a valuable national resource and warrants continued investment.

The role of gardens and parks as innumerable components in a green web, supporting and at times replacing the fragile network of natural ecosystems, has been little explored in this report. However, these millions of landscapes, large and small, will have a vital role to play in reinforcing a system of ecological corridors through which wildlife can migrate in response to climate change.

Lastly, the beneficial effects of good soil management and maintenance of a healthy plant cover in coping with climatic extremes in gardens provides a model which, if followed on a national and international scale, will do much to slow the pace of climate change and to reduce its impacts.

Adapting gardens to the impacts of climate change will incur additional expense and labour. However, by investing in gardens and by adopting good gardening principles on a wider scale, the UK will be able to address the implications of climate change for our gardens, and give future generations the opportunity of experiencing the pleasure of sitting under a tree that is some 200-300 years old.

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Appendices

Climate change questionnaire

The questionnaire below was sent to fourteen gardens. Replies were received from:

Nick Jarvis
Alfriston Clergy House, Sussex
Professor John Parker
Cambridge Botanic Garden
David Lock
Chirk Castle and Garden, Wrexham
Professor Charles Stirton
National Botanic Garden of Wales, Llanarthne
Peter Hall
Powis Castle and Garden, North Wales
Chris Bailes
Rosemoor, Devon
Dr David Rae
Royal Botanic Garden, Edinburgh
Dr Nigel Taylor
Royal Botanic Gardens, Kew, Surrey
Sarah Cook
Sissinghurst Castle Garden, Kent
Barry Champion
Trelissick, Cornwall
Jim Gardener
Wisley, Surrey

Climate Change and Gardens

1. What is the planning time-frame within which you operate? How far ahead do you plan for the garden?

2. What are the general objectives of any forthcoming changes? Expansion, upgrading of facilities, increased diversity of facilities, to attract more visitors, to widen visitor base, more economy /efficiency of operation, increased historical authenticity etc

3. What are the major influences on forthcoming changes? Budgetary restraints, need to attract visitors, difficulties in staff recruitment, new historical evidence, increasing emphasis on education etc.

4. What is your next major development?

5. To what extent does sustainability feature in your planning? Please tick one:
    a. Central driving force
    b. Important consideration
    c. Of some importance, but other factors more important.
    d. Minor importance
    e. No importance

6. To what extend does the need to respond to climate change feature in your planning? (Please tick one)
    a. Central driving force
    b. Important consideration
    c. Of some importance, but other factors more important
    d. Minor importance
    e. No importance

7. Can you cite recent (past 5 years) examples of extreme weather events which have affected your garden?

8. In your experience, are extreme weather events more or less frequent than they used to be?

Continues overleaf

9. Below are some predictions about climate change over the next 20-50 years based on the UKCIP98 climate change scenarios. What positive and/or negative effects on your garden do you anticipate from these predictions if they prove to be true?
    a. A mean temperature rise of 2-5°C. (giving the south of England a climate similar to that of Bordeaux, and the north of England a climate similar that of Surrey).
    b. A 3-fold increase in the number of hot days (above 27°C or 80°F)
    c. 5-10 days each year with temperatures above 40°C or 105°F
    d. A longer growing season – perhaps ten days earlier start and later finish
    e. Substantial reduction in number of days with frost (to near nil in parts of Southern England).
    f. 20% increase in winter rainfall
    g. 20% decrease in summer rainfall
    h. Increasing uncertainly of rainfall: alternation of droughts and heavy rainstorms
    i. Increased incidence of strong winds
    j. 50cm rise in mean sea level
    k. Any other direct impacts of climate change

10. Do you see an overall benefit, an overall deficit, a balance of advantages and disadvantages or no impact for your garden in each of these scenarios? (Please write "ben", "def", "bal" or "no" as appropriate below.
    a. A mean temperature rise of 2-5°C (giving the south of England a climate similar to that of Bordeaux, and the north of England a climate similar that of Surrey).
    b. A 3-fold increase in the number of hot days (above 27°C or 80°F)
    c. 5-10 days each year with temperatures above 40°C or 105°F
    d. A longer growing season – perhaps ten days earlier start and later finish
    e. Substantial reduction in number of days with frost (to near nil in parts of Southern England).
    f. 20% increase in winter rainfall
    g. 20% decrease in summer rainfall
    h. Increasing uncertainly of rainfall: alternation of droughts and heavy rainstorms
    i. Increased incidence of strong winds
    j. 50cm rise in mean sea level
    k. Any other direct impacts of climate change

11. Would the overall impacts on your garden of the climate change phenomena described above be beneficial, damaging or neutral?

12. Are you (or are you likely to be) taking any steps in your garden to adapt to anticipated impacts of climate? If so, what steps?

13. Are you (or are you likely to be) taking any steps to reduce the causes of climate change?

14. Do you maintain records of;
    a. climatic data?
    b. phenological data?
    c. visitor numbers?

Many thanks for your time. The results of this questionnaire will be published, as part of a report on the impacts of climate change on gardens, in 2002.
Richard Bisgrove

Glossary

Acclimation: literally "becoming adapted to", as when plant response to higher carbon dioxide concentrations decrease because the plant has adapted to the new situation. **Acclimation** is used in plant physiology in preference to "acclimatisation" which strictly means "becoming used to a new climate".

Albedo: reflectivity of a surface. A surface (for example a dark soil) which has an albedo of zero absorbs all the light falling on it. A surface with an albedo of one (for example, fresh snow) reflects all the light falling on it.

Arthropod: animals (usually small animals) with segmented bodies and jointed limbs. Arthropods include insects, mites and millipedes, for example.

Assimilates: in the context of plants, materials such as carbohydrates and proteins, which the plant synthesises and then incorporates into its tissues.

C3/C4 plants: photosynthesis in **C3 plants** (most plants from temperate regions) involves 3-carbon molecules building into sugars. Some (mainly tropical) plants have a different mechanism involving 4-carbon molecules, with the advantage that they are able to store then release carbon dioxide within the leaf so that photosynthesis can take place while stomata are closed. These are referred to as **C4 plants**. A full explanation cannot be given in simple terms. The topic of C3/C4 plants has been referred to only in passing in the text, because temperatures much higher than those anticipated in the UKCIP02 scenarios would be needed to make significant use of C4 plants in UK gardens.

Clone: a population of genetically identical plants (and now animals). Clonal plants are produced asexually, by vegetative propagation, rather than from seed.

Development: see **Growth**

Dicotyledon(ous plant) (abbr. **Dicot**): there are two major divisions in the plant kingdom. Those which emerge from the seed with two seed-leaves (cotyledons) are known as **dicotyledons** or **dicots**. Most of these have broad true leaves. Those which emerge from the seed with one cotyledon are known as **monocotyledons** or **monocots**. Most of these, such as grasses and bulbs (narcissus, crocus, lily) have narrow leaves.

Dry matter: the substance (including carbohydrates and proteins) of plants as measured after drying the plant in an oven to remove all water. Dry matter includes the assimilates (q.v.) within the plant and the structural material of the plant.

Evaporation: conversion of (liquid) water to water vapour. Evaporation from plant leaves is often termed **transpiration**; the combination of evaporation from soil and leaf surfaces, and transpiration from within the leaf is termed **evapo-transpiration**. The amount of water which could theoretically be evaporated in particular climatic conditions is the **potential evaporation**, or **potential evapo-transpiration**. Actual evaporation is usually less than potential evaporation because the amount of water available for evaporation is reduced as the soil dries and plants become stressed.

Growth: the increase in size of the plant. **Development** refers to changes of state within the plant, such as the production of leaves, the formation and expansion of flowers or the onset of dormancy.

Legume/leguminous plant: a plant of the family Leguminosae, with pea or bean-like flowers. Legumes include herbaceous plants such as sweet pea, shrubs such as broom (Cytisus) and gorse (Ulex), and trees such as Robinia and Laburnum. Legumes have root nodules in which symbiotic bacteria (q.v.) live. These are capable of converting atmospheric nitrogen into nitrates.

Monocotylendon(ous **plant**) (abbr. **Monocot**): see **Dicotyledon**

Mycorrhiza (plural **Mycorrhizae**): fungi which live in association with plants (especially many trees). The fungus receives assimilates (q.v.) from the plant roots and supplies the roots with minerals obtained from the soil through its extensive hyphae. Mycorrhizae are especially important in very acid or very poor soils as they are capable of extracting minerals which would be unavailable to the tree itself.

Multivoltine: having several generations each year.

Nematode: eelworm. A microscopic, worm-like creature. Some nematodes are harmful to plants, causing deformation of roots, stems or leaves. Others are beneficial, attacking pests such as vine weevil.

Phenology: the study of organisms as affected by climate, especially the timing of seasonal phenomena such as leaf emergence or flowering of plants, or seasonal arrival of migrant birds and butterflies.

Phenotype: the observable characteristics of a plant or animal produced by the interaction of its genetic make-up and the environment.

Photoperiod: length of the light period, usually in relation to a 24 hour day. ‘Long-day’ plants will respond (for example by flowering or emergence form dormancy) to photoperiods above a critical value. ‘Short-day’ plants will develop in response to short or declining photoperiods.

Pneumatophore: a woody outgrowth on the roots of swamp cypress (*Taxodium distichum*) which grows above the surface of water or wet soil to conduct oxygen down to the root system. Pneumatophores are commonly called ‘knees’.

Potential evaporation: see **Evaporation**

Ppm(v): parts per million. Gas concentrations are usually measured as parts per million by volume (**ppmv**) while concentrations of substances in solution or in mixtures of solids are measured in parts per million by mass (**ppmm**).

Precipitation: the amount of water reaching the soil surface, whether as rain, hail, snow or settlement of water droplets from mist and fog. A more inclusive term than ‘rainfall’.

Provenance: the location from which seed is obtained. Provenance is important because there can be wide variations within a species as a result of evolution in different climatic zones. Spruce trees from seed obtained from a population in Alaska, for example, will be much slower growing and have a shorter growing season, but be much more cold tolerant than seed collected from the same species in more southerly regions when both are grown in the same place.

Sink: plant physiologists use the term **source** to refer to the sites within the plant where assimilates (q.v.) (especially products of photosynthesis) are formed and **sink** to refer to the sites to which assimilates are transported for use. The presence of an active **sink** in the plant (such as actively growing tips or developing flower buds or seeds) will stimulate the plant to photosynthesise more rapidly.

SSSI: Site of Special Scientific Interest. A statutory designation of land, sometimes an extensive area of a particular habitat and sometimes a small area containing a rare plants or animals.

Stoma (plural **stomata**): small pores in the plant leaf (and to a lesser extent on other surfaces), through which water vapour and gases such as carbon dioxide and oxygen diffuses into and out of the plant. The stoma is bordered by guard cells which open and close the pore in response to changes in water vapour and carbon dioxide concentration. **Stomatal aperture** is the size of the pore.

Symbiosis: coexistence for mutual benefit. Mycorrhizae (q.v.) and trees have symbiotic relationships, as do the bacteria in root nodules of leguminous plants (q.v.) with their host plant.

Synchrony: (= same time). Two events which are organised so that they happen together are said to be synchronous, or to exhibit synchrony. In biology, synchrony evolves to ensure that a food source is available in suitable condition to sustain another organism, as when the hatching of a caterpillar is synchronised with the emergence of the leaves on which it needs to feed.

Thermal growing season: the longest period within a year that satisfies the twin requirements of (i) beginning at the start of a period when the daily average temperature is greater than 5.5°C for five consecutive days and (ii) ending on the day prior to the first subsequent period when the daily average temperature is less than 5.5°C for five consecutive days. The actual growing season will depend on the type of plant, on its emergence from dormancy and other factors but **thermal growing season** provides a precise meteorological measure of the way in which growing conditions vary from year to year.

Thermal time: the 'amount of heat' received by a plant. Thermal time is the product of the number of days and the number of degrees above a particular minimum for the process under consideration. The timing of many plant growth responses, such as breaking of dormancy or initiation of flowers, is determined by thermal time.

Transpiration: see **Evaporation**

Xerophyte (adj. **Xerophytic**): a plant adapted to very dry conditions, by its compact form, thick, waxy leaf surface or other characteristics.

Xeriscape: the use of xerophytic plants to create gardens which have low water requirements. 'Dry gardening'.

Examples of climate change scenarios for three case study gardens

In the main report, the impacts of climate change are dealt with component by component, and in terms of regional scenarios. What matters in a garden is the combination of factors at a particular spot. In order to give some feel for these local impacts, three locations have been chosen, in the north, east and south west of the UK. For each location, basic meteorological data for 1961-90 are presented (Wheeler and Mayes, 1997) and changes anticipated by the medium high emissions scenario for the 2080s estimated by reference to the UKCIP02 scenarios (Hulme *et al*., 2002).

To choose a representative site for the north of the UK, in Scotland, is impossible because the deeply indented coastline and generally steep topography mean that the local influence of the sea and of changing altitude is always present, as anyone who has travelled the 24km (15 miles) from the cold rocky summit of Ben Eighe National Nature Reserve to the palm filled garden at Inverewe will appreciate. However, Ardtalnaig, south of Ben Lawers on Loch Tay has been selected as an inland site at low altitude on the southern edge of the highlands. Its climate is moderated by Loch Tay, which is of sufficient depth that it never freezes, but in other respects it is as 'average' as it is possible to find in this varied landscape.

Cambridge is in the driest part of England, but its climate is representative of a broad swathe of eastern England.

Torquay is a coastal location, but has been chosen as more representative of the south west as a whole than would be a more westerly site. It is also more characteristic of the gardened south west than are places farther inland, where the high moors, thin soils and atypically severe climate impose their local limitations on gardening.

Tables A3.1, A3.2 and A3.3 show January and July data for temperatures and precipitation at each location, and the changes to these which are anticipated by the UKCIP medium high emissions scenario for the 2080s. Current January and July precipitation figures are added to give some indication of changes in annual rainfall (data have not been calculated separately for every month of the year) and the ratio of January to July precipitation is presented to give some indication of the change in seasonal distribution of rainfall.

To avoid tedious repetition of qualifications, in the following descriptions the terms "now", "currently" or "at present" are used, slightly incorrectly, to refer to 1961-90 baseline conditions. References to future conditions throughout the text apply to the UKCIP02 medium high emissions scenario for the 2080s.

A3.1 Ardtalnaig, Loch Tay, Central Scotland

In Ardtalnaig the winter temperature, currently not dissimilar to that of Cambridge, is anticipated to rise by 2°C. The minimum may also increase from an average of 0.4°C, barely above freezing, to 2.4°C, somewhat cooler than Torquay now. In much of Scotland temperature rise could result in mean minimum temperatures changing from negative (below freezing) to positive.

Present July temperatures are 2-3°C below those of Cambridge and Torquay. With an anticipated rise of about 3°C, July temperatures in the 2080s in Ardtalnaig would be warmer than are Cambridge and Torquay at present.

In common with most of the western half of the UK, precipitation in Ardtalnaig falls mainly in the winter months. Current January precipitation is more than twice that of July. With an anticipated 20% increase in precipitation in an already wet winter, but a 35% decrease in a relatively dry summer, total precipitation (currently 50% higher than Torquay and 250% higher than Cambridge) would be little altered but the January:July ratio could change from 2.3:1 to 4.2:1.

Although the magnitude of these changes is less than in the east or south west, the decrease in precipitation in an already dry summer, combined with increasing temperatures, is likely to have a significant impact, especially in gardens on steep slopes and with shallow, rocky soils, where continuous throughput of water is necessary for the growth of the drought sensitive plants which are characteristic of Scottish gardens.

Whether increased winter precipitation is a bonus (replenishing soil moisture depleted in summer) or a problem (saturating soils and causing erosion or flooding) will depend on the management of water within the garden. The total amount of water is likely to be virtually unchanged but the amount available to plants will diminish because of higher evaporation rates at higher temperatures. The need to conserve winter supplies in order to compensate for summer deficits will therefore be very important.

A3.2 Cambridge, Eastern England

In Cambridge, January temperatures, and especially January minima, are currently similar to those in Ardtalnaig. An increase of about 2.8°C in winter temperatures by the 2080s would result in January temperatures higher than those currently experienced in Torquay.

Current July temperatures are similar to those of Torquay, though as a result of slightly higher maximum temperatures and slightly lower minimum temperatures in Cambridge's more continental climate. An increase of 4.5°C in summer tempera-

Table A3.1: Ardtalnaig, Loch Tay, Central Scotland

	1961-90 mean	Change in med high scenario for 2080s	Estimated figures for the 2080s
January		**Winter**	
Max temp (°C)	5.2		7.2
Min temp	0.4		2.4
Mean	2.8	+2°C	4.8
Precipitation (mm)	159	+20%	190
% of annual total	12.7%		
July		**Summer**	
Max temp (°C)	18.6		21.9
Min temp	10.0		13.3
Mean	14.3	+3.3°C	17.6
Precipitation (mm)	69	-35%	45
% of annual total	5%		
Precipn: Jan+July	**228**		**235**
Precipn: Jan:July	**2.3**		**4.2**

tures will not change that comparison. In terms of temperature, Cambridge and Torquay will be similarly affected.

In common with much of the eastern half of the UK, precipitation is distributed evenly throughout the year. July, with 8.7% of the annual precipitation, is slightly wetter in terms of precipitation than January, with 7.8%, although much higher evaporation rates with high summer temperatures mean that water is less available to plants in July.

By the 2080s, winter precipitation is anticipated to increase by 25%, but this could only mean an 11mm increase and would be insufficient to compensate for increased evaporation, given the mean temperature change from 3.65 to about 6°C. Summer precipitation would be nearly halved. Total annual precipitation decreases by a small total amount, but the ratio of winter:summer precipitation could increase from 0.9:1 to about 2:1.

The combination of higher temperatures and reduced precipitation will result in severe drought conditions in many years and accentuate the mediterranean climate which Cambridge already experiences to some extent.

What is not shown in the table of climate data is the fact that much of Cambridgeshire, Norfolk and Lincolnshire is very low lying, some of it at or below sea level. The landscape, and especially water resources, have been intensively managed for agriculture. However, as fertile peat soils have been lost by oxidation or wind-blow and as sea levels rise, land use and nature conservation policies have moved to planned retreat from the most vulnerable areas.

A3.3 Torquay, Devon

Torquay has a mild climate, several degrees warmer in winter than Cambridge and Ardtalnaig. Minimum January temperatures in Torquay are similar to mean

Table A3.2: Cambridge, Eastern England

	1961-90 mean	Change in med high scenario for 2080s	Estimated figures for the 2080s
January		**Winter**	
Max temp (°C)	6.5		9.3
Min temp	0.8		3.6
Mean	3.65	+2.8°C	6.45
Precipitation (mm)	43	+25%	54
% of annual total	7.8%		
July		**Summer**	
Max temp (°C)	21.5		26.0
Min temp	11.7		16.2
Mean	16.6	+4.5°C	21.1
Precipitation (mm)	48	-45%	26.5
% of annual total	8.7%		
Precipn: Jan+July	**91**		**80.5**
Precipn: Jan:July	**0.9**		**2.0**

January temperatures in Cambridge. In summer the differences are much less. Maximum July temperatures are lower than in Cambridge, though the mean is very slightly higher.

An anticipated 2.5°C rise in winter temperatures (compared with about 2.8°C in Cambridge) represents some closing of the difference but Torquay remains 2-4°C warmer than the other two places. Anticipated summer increases of about 4°C would result in 2080s summer temperatures again very similar to those of Cambridge.

As in Ardtalnaig, precipitation in Torquay falls mainly in the winter months. January, with 114mm, has 2.5 times the July precipitation of 46mm. A 20% increase in anticipated winter precipitation would result in an extra 23mm of rain, but increased evaporation would mean that soil moisture content in winter may increase by only 0-4%. July precipitation in Torquay is similar to that in Cambridge and, as in Cambridge, the 2080s scenario anticipates nearly halving this amount. Soil moisture deficit could increase by 40-50%.

The overall effect of moderate decrease in the relatively high winter precipitation and a substantial decrease in the much smaller summer precipitation is to leave the total unaltered, but the ratio of winter:summer precipitation could increase from 2.5:1 to 5.5:1. On thin, shallow soils and free draining slopes especially, water shortage in summer will be severe. In the past, lack of major aquifers or rivers to supplement precipitation and the extra demand on supplies caused by a marked increase in summer population of holiday makers has often led to water shortages. The building of new reservoirs has been strenuously opposed because of their impacts on a beautiful landscape. These problems can only increase as climate change continues.

One positive aspect of climate change in the south west is that soil moisture content is expected to increase by only a very small amount, perhaps 0-

Table A3.3: Torquay, Devon

	1961-90 mean	Change in med high scenario for 2080s	Estimated figures for the 2080s
January		**Winter**	
Max temp (°C)	8.8		11.3
Min temp	3.4		5.9
Mean	6.1	+2.5°C	8.6
Precipitation (mm)	114	+20%	137
% of annual total	12.7%		
July		**Summer**	
Max temp (°C)	20.6		24.8
Min temp	13.1		17.3
Mean	16.85	+4.2°C	21.05
Precipitation (mm)	46	-45%	25
% of annual total	5.1%		
Precipn: Jan+July	**160**		**162**
Precipn: Jan:July	**2.5**		**5.5**

4% above current levels. Soil saturation which has been a feature of recent exceptionally wet winters and which has led to root rot of many plants, especially magnolias, seems unlikely to become the norm. Gardeners will not be facing a losing battle if they improve soil drainage to contend with the problems caused by what should be infrequent very wet winters.

Another possible advantage is that the summer climate, although posing serious challenges for the cultivation of gardens, will improve the prospects of the south west as a holiday destination and improve the prospects for major gardens relying on tourism for their livelihood.

A3.4 Summary

In all three locations, the main challenge will be in coping with much drier conditions in the summer. In the north, higher winter rainfall will assist in overcoming the problem if the winter surplus can be stored. In the east, precipitation will decrease throughout the year and higher evaporation rates will exacerbate water shortages. In the south west, annual precipitation will be little altered by climate change but higher evaporation rates will reduce the amount of available water. If the UKCIP02 scenarios are reasonable approximations of climate change, it is unlikely that excessive winter wet will be an increasing problem, although there will, of course, be some very wet winters (and indeed some very wet periods in some summers) as in the past.