Chapter 1 Climate and climate change

This chapter serves by way of an introduction to examine the climate and its relationship to plant distribution, climate change and elevated carbon dioxide levels and their effects, mainly on the flora and fauna but also on sea-level, and soil processes. This gives information relevant to more detailed analysis in the later chapters.

1.1 Climate

Studies of the earth embrace the solid 'lithosphere', water in the liquid 'hydrosphere' and the frozen 'cryosphere', the mainly gaseous 'atmosphere' and the life forms of the 'biosphere' (Critchfield, 1983). The study of weather and climate focuses on the envelope of gases, but continuous interchanges between the 'spheres' produce an integrated environment. Weather is defined as 'the state of the atmosphere at any one place or time' and includes humidity, temperature, sunshine hours, cloud cover, visibility, and precipitation. Climate is not just 'the average weather conditions of a region' but includes diurnal and seasonal variations and extreme fluctuations (Critchfield, 1983).

Climatology is the science that seeks to describe and explain the nature of climate, why it differs from place to place, and how it is related to other elements of the natural environment and to human activities. Physical climatology examines the elements and processes that determine the spatial variations in climate. These are described by regional climatology which implicates the concept of scale (Yoshino, 1975). 'Macroclimate' describes the conditions over large areas, e.g. a country, 'mesoclimate' describes those from 10 to 100 km in size, e.g. a valley, whilst 'microclimate', measured in metres or tens of metres, specifies the properties of the lowest layers of the atmosphere, the 'boundary layer' (Oke, 1987). This introduces the third major division, applied climatology, which explores the relation of climate and other phenomena (e.g. soils), considering its effect on human welfare and the possibility of modifying climates to meet human needs.

For the last several thousand years, Britain has enjoyed a maritime, temperate climate (Chandler & Gregory, 1976). Due to the powerful influence of the Atlantic Ocean, there are no great extremes of heat, cold, drought or flood. Regionally, the northern areas of Britain tend to be cooler, wetter, more windy and less sunny than the southern counties (Smith, 1980). Local variations in temperature, cloud cover, wind and

precipitation may occur in relation to altitudinal, maritime, or topographic influences. Air temperatures, solar radiation and rates of evapo-transpiration decrease, but wind speeds and cloud cover increase with altitude. Around the coast, the seasonal amplitude in temperature is much less than that inland and the climate is said to be oceanic. Wind speeds measured at coastal sites are very high and damage to property and crops is common. In a Derbyshire dale, the mean summer temperature was 3 °C higher on a south- than a north-facing slope (Rorison, 1990), this variation being equivalent to a latitudinal shift of hundreds of kilometres (Grace, 1987).

1.2 Climate and plant distribution

Abiotic relationships (i.e. physiological tolerances) are the primary factors determining whether any organism can exist in a certain environment. Temperature (Sutcliffe, 1977) and light (Whatley & Whatley, 1980) affect plant metabolic processes and thereby germination, growth and reproduction. Species and ecotypes vary in their tolerances of low and high temperatures and light intensities and therefore have different geographical distributions (Woodward, 1987a).

Raunkiaer (1934) pointed out that tropical forests contained a wide spectrum of life-forms but, in extreme climates, the spectrum became reduced. Boundaries to the distribution of plant life forms and species often coincide with isometric lines of climatological variables (Grace, 1977) especially temperature. Woodward (1987) states that the poleward spread of a particular physiognomic type of vegetation is strongly controlled by minimum temperature and the physiological ability to survive low temperatures (Sutcliffe, 1977; Bliss, 1956, 1962). Vegetation structure converges in floristically distinct yet climatically analogous sites, e.g. Mediterranean type ecosystems of California, Chile (Parsons & Moldenke, 1975) and South Africa (Cowling & Campbell, 1980). Trees are restricted to those areas of the world where the mean summer temperature exceeds 10 °C. Species with a pronounced northern distribution may have a winter chilling requirement for germination which is not met at southern latitudes. Many species appear to be restricted by low summer temperatures (Figure 1). The distribution of Cirsium acaule (stemless thistle) near its northern limit in the UK is mainly on south-facing slopes (Piggott, 1974). In Tilia cordata (small-leaved lime), individuals at the northern limit of distribution do not set seed unless the summer is an especially warm one (Piggott & Huntley, 1978, 1980, 1981).
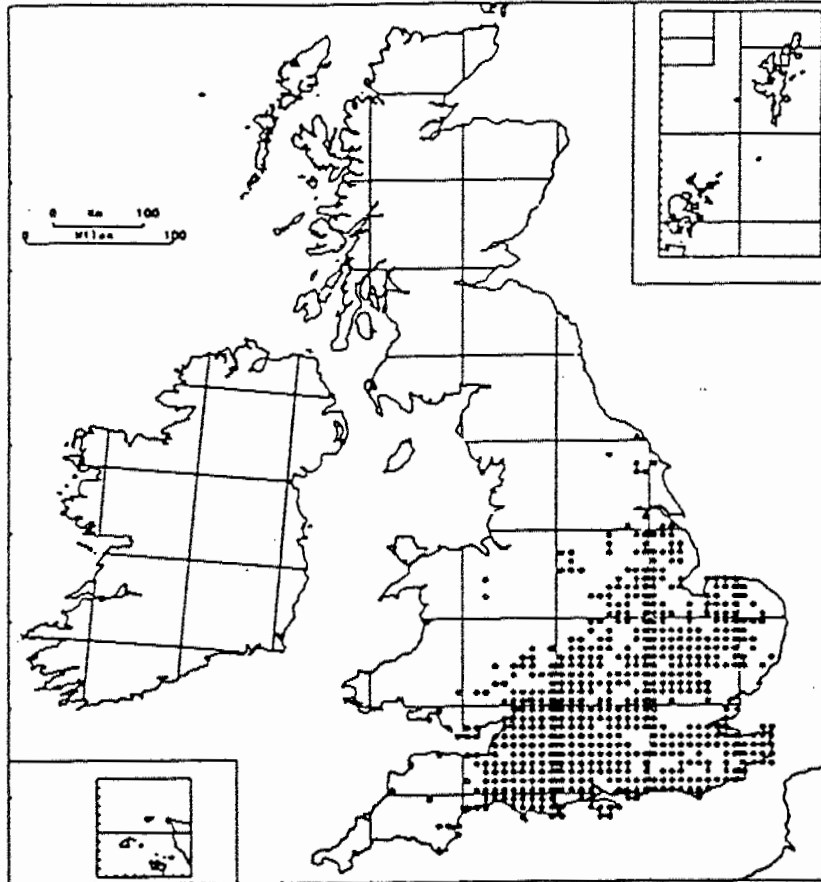
Figure 1. Distribution of stemless thistle (Cirsium acaule) in the British Isles (from Perring & Walters, 1976)

1.3 Climate change

Climate monitoring may not have been totally accurate (Strangeways, 1991) and representative (Michaels, 1991), but global records since 1861 show a significant, but irregular temperature rise of up to 0.6 °C (Jones et al., 1986) which appears to exceed natural trends. Global temperatures reached their highest levels during the 1980s which included many of the warmest years on record. It is now widely considered that this global warming may be the result of increasing 'greenhouse gas' concentrations.

1.3.1 Greenhouse gases

Carbon dioxide (CO_2) is the main gas in the atmosphere, which is transparent to incoming short-wave solar radiation, but absorbs outgoing infra-red radiation. This is termed the 'greenhouse effect' but actually bears no semblance to the manner in which a greenhouse operates (Lee, 1973). The other greenhouse gases are methane (Pearce, 1989), nitrous oxide, ozone, and certain chlorofluorocarbons (Fowler, 1990; Shine, 1989). Molecule-for-molecule these are more effective absorbers of infra-red radiation, but CO_2 occurs at much higher concentrations and currently contributes about half of the greenhouse effect (Cannell, 1990a). Ice core data show that in the middle of the last century, before the industrial revolution, the concentration of CO_2 was 275+10 ppm (Neftel et al., 1985; Pearman et al., 1986). Data collected at Hawaii's Mauna Loa Observatory show an indisputable increase from 315 ppm in 1958 to 350 ppm in 1988 (Houghton, 1987; Gribbin, 1988). Atmospheric CO_2 concentrations are rising (Figure 2) because carbon locked up in fossil fuels and tropical forests is being released by burning and decomposition (Woodwell et al., 1983; Houghton et al., 1983). Molecule-for-molecule, methane traps 25 times as much of the Sun's heat in the atmosphere as CO_2. Its atmospheric concentration is also rising at almost 2% per year. Sources include rice paddies, wetland and tundra, ruminant digestion, biomass burning, waste tips and termites (Pearce, 1989).

1.3.2 Predictions of climate models

Despite the potential role of terrestrial vegetation (Schlesinger, 1990) and marine plankton (Williamson & Gribbin, 1991) to act as sinks, CO_2 abundance is expected to reach 600 ppm in the next century even if growth of fossil fuel use is slow (Hansen et al., 1981). Two approaches have been used to predict the future climatic changes which might result. These are: numerical modelling using general circulation models (GCMs)
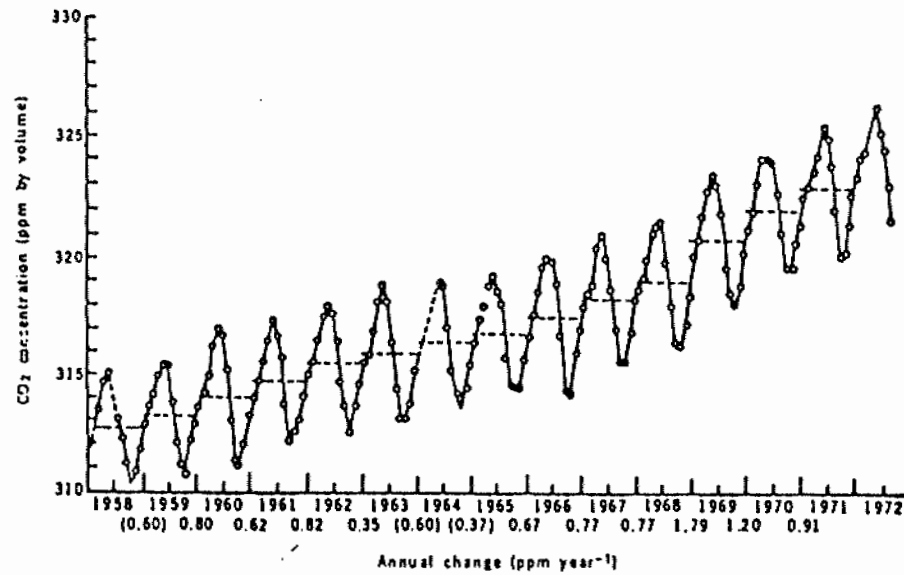
Figure 2. Mean monthly CO_2 concentrations at Mauna Loa, Hawaii.
Horizontal dashed lines indicate yearly average values (from Hobbs et al., 1974)

and the use of past warm periods as analogues for the future (Hecht, 1990). The Intergovernmental Panel on Climate Change (IPCC: Houghton et al., 1990) ran some twenty numerical simulation models to equilibrium for the period 1850-2050 assuming a doubling of CO_2 during that period. The major predictions of climate models are a general warming of the earth's surface with stronger warming at higher latitudes (Hansen et al., 1981) and in winter (Strangeways, 1991). This increase could be 2 to 3 ºC, a change as great as any which has occurred in the past 10,000 years (Wigley et al., 1980). This is likely to increase global rainfall by up to 10% due to greater evaporation from the sea and land (Pearce, 1990). Large regional variations in temperature and precipitation will accompany global warming including the creation of drought-prone regions in North America and central Asia (Hansen et al., 1981; Pearce, 1990).

1.3.3 Sea-level rise

Another immediate effect of an increase in global mean temperatures is a rise in sea-level (Warrick & Oerlemans, 1990; Lutjeharms & Valentine, 1991). Sea level has risen 15 cm during the 20th century mainly due to the thermal expansion of sea water (Boorman, 1990). Only a little extra water has been added to the sea, by melting glaciers on mountains at low latitudes. A global warming of 2 ºC, possible within 40 years, will increase sea level by a further 30 centimetres (Gribbin, 1988). Paradoxically, at present, polar ice caps may be increasing in size (Davidson, 1992). This is because more moisture is evaporating at low latitudes, and this is falling as snow at the poles, where it is still cold. Some scientists fear that the entire West Antarctica ice sheet might 'collapse' into the ocean raising sea levels by 5 m or more (e.g. Mercer, 1978).

1.4 Increasing CO_2 and plant physiology

This section discusses the influence on plant processes of an increase in atmospheric CO_2 concentrations from the current value of approximately 350 ul l^{-1} to 500-700 ul l^{-1} as is expected to occur by the end of the 21st century.

In the majority of short-term experiments, an increase in CO_2 concentration has resulted in increased assimilation rates of between 10% and 150% (Eamus, 1990). The average response of stomatal conductance (g_s) to a doubling of CO_2 is a decrease of 10-60%. The net effect is an increase in water use efficiency (W.U.E.) defined as the amount of water transpired per unit CO_2 fixed. In addition to changes in conductance caused

by variation in stomatal aperture, for a range of tree and herbaceous species, stomatal density has been shown to decrease in response to growth at elevated CO_2 concentrations (Woodward, 1987; Woodward & Bazzaz, 1988).

Growth responses to elevated CO_2 have generally been positive. The leaf number, area, weight and weight per unit area of broad-leaved trees and conifers increased by 20 to 120% (Eamus & Jarvis, 1989). La Marche et al. (1984) found increased widths of annual rings of trees in subalpine habitats in the western United States during recent decades. The increased tree growth rates observed exceeded those expected from climatic trends, but were consistent with global trends in CO_2. Annual plants may develop more quickly under elevated CO_2, reaching full leaf area, biomass and flower and fruit production sooner than plants at ambient CO_2. Garbutt and Bazzaz (1984) studied the effects of elevated CO_2 on timing and patterns of flower production, flower and fruit abortion, and fruit and seed production between and within three herbaceous annual species. They found that Phlox drummondii and Datura stramonium flowered earlier and individual seed weight of Abutilon theophrasti increased under high CO_2. There is also some evidence of delayed senescence under elevated CO_2.

Elevated CO_2 levels can compensate substantially for the impact of environmental stress. Compensation for low levels of light and nutrients and for water stress in seedlings may enhance their ability to grow and become established. Clearly, if this effect varies between species, species competition and hence natural or unmanaged ecosystem structure and composition may be expected to change. Williams et al. (1986) grew three upland and three lowland species together, and both quantum flux density and CO_2 level directly influenced the relative weight of each species in a complex way. Some ecosystems such as temperate grasslands contain a mixture of C_3 and C_4 plants. Elevated CO_2 could affect the competition between them. As the CO_2 concentration increases, C_3 plants should do progressively better than C_4 plants, unless there is water stress. A number of studies have shown just these results (Carter & Peterson, 1983). For example, Bazzaz and Carlson (1984) studied the competition between C_3 and C_4 herbaceous plants grown under two moisture levels and three levels of CO_2 (300, 600 and 1200 ppm). The C_3 species grew progressively more rapidly than the C_4 species as the CO_2 and moisture levels increased.

1.5 Consequences of climate change for the UK

Historical evidence indicates the extent of previous climate change effects (Hooper, 1990). However, the projected rate of warming is fast compared with past global warmings, perhaps fifty times as fast. Furthermore, predicted increases in the frequency of such extreme climatic events as fires, hurricanes, and droughts may be more important than temperature change itself in changing patterns of biological diversity (Wigley, 1985; Marrs, 1990). Recent examples in Britain include the October gales of 1987 affecting the southern woodlands and the hot, dry summer of 1976 affecting heathlands, through heather death and 'accidental' fires (Marrs, 1986).

1.5.1 General ecological effects

Many ecological systems will be dramatically changed (Pain, 1988). Large shifts will occur in the ranges of species, hundreds of kilometres northwards in the north temperate zone, causing ecological communities to break up and reassort. The ability of a species to shift its range will depend on its intrinsic colonizing abilities and the existence of barriers to dispersal. Because species will shift at different rates in response to climatic change, communities will often dissociate into their component species. If the rate of climatic change is so fast that the preferred climate travels north faster than a species can follow, extinction is possible (Peters, 1992). Because warming will be much greater at higher latitudes, arctic ecosystems will experience even greater warming and ecological change than temperate ecosystems (Emanuel et al., 1985). Boreal forest was projected to decrease by 37% in response to a global warming of 3 °C.

1.5.2 Effects on natural vegetation

The spatial pattern in the vegetation of the British Isles is often strongly correlated with climatic variables. If the climate changes radically profound effects can be expected on the native flora (Hendry & Grime, 1990; Marrs, 1990) as well as on agriculture and forestry (Adams et al., 1990, Parry, 1992). These effects will appear as changes in the timing of seed germination and flowering in response to drought, extremes of winter and summer temperature and changes in the length and distribution of the growing season. A likely consequence will be the expansion of species with a predominantly Mediterranean distribution, recession of species with a northern distribution, extension of lowland species to higher latitudes, and retreat of upland and montane species (Hendry & Grime, 1990). The rate of vegetation change will be closely related to the lifespan and dynamics of

the component populations. The survival of species of trees depends on how well they disperse their seeds. A tree that drops its seeds to the forest floor to lie dormant until a gap appears in the forest canopy may not be able to track the moving climate. Trees with light, windblown seeds or seeds carried by animals stand a better chance of covering the necessary distances (Pain, 1988).

1.5.3 Effects on forestry

Any climatic change which occurs over the next 50 years will occur within the lifetime of many trees now growing in the UK. There will be insufficient time to change the species or provenances to keep pace with the changing climate. The natural distributions of some native tree species in Britain seem to be determined by temperature. The small-leaved lime (Tilia cordata) does not regenerate naturally north of the Lake District, apparently because the temperatures are too cool in spring for pollen tube growth (Piggott & Huntley, 1978, 1981), while the bird cherry (Prunus padus) is found almost exclusively in northern and upland Britain. Other examples include the field maple (Acer campestre) and apple (Malus sylvestris) respectively (Cannell et al., 1989). Cannell et al. (1989) list many broadleaved species which might spread northwards following climatic warming, and those species currently growing in more southerly regions of Europe and elsewhere that might grow well in southern England. The results of tree breeding may be of limited value if the climate changes substantially in the 50-80 year interval between progeny testing and the growth and harvesting of the genetically improved trees.

The buds of many woody perennials need to be chilled in winter to release dormancy. If the buds are not fully chilled they will require a large thermal time (heat sum in day degrees) to grow to budburst, and growth will be late, and may be poor or abnormal. Studies on 15 woody species in Britain showed that species like Sitka spruce (Picea sitchensis) and beech (Fagus sylvatica), which flush relatively late, have a high chilling requirement and are likely to flush equally late after warm winters (Cannell & Smith, 1986; Murray et al., 1989). By contrast, species like hawthorn (Crataegus monogyna) and some poplars (Populus spp.), which flush early at present are likely to flush even earlier given warm winters and springs. Clearly, any increase in peak windspeeds, unseasonal frosts or increased hazards from pests or fire will be damaging to forests. If it becomes drier, there will almost certainly be an adverse effect on tree growth, as evidenced following the summers of 1976 and 1989.

1.5.4 Effects on invertebrates

Studies have shown that there is a linear relationship between temperature and insect development, survival, growth and reproduction. Insect pest species might be expected to become more abundant or increase earlier in the year following global warming (Watt et al., 1990). However, the situation is complicated by changes in insect-plant (e.g. host phenology, plant quality) and predator-prey interactions. The geographical distributions of many native insect species coincides with the distributions of climatic variables. Even small temperature changes of less than 1 °C within this century have been observed to cause substantial range changes. For example, the white admiral butterfly (Ladoga camilla) and the comma butterfly (Polygonia calbum) greatly expanded their ranges in the British Isles during the past century, as the climate warmed approximately 0.5 °C (Ford, 1982). Following climatic warming, many of the 20,000 species of insects in the UK would expand their natural ranges, especially as the majority of invertebrate groups occur in the south of Britain where the climate is mildest (Watt et al., 1990). Thus, grasshoppers and crickets have 31 species within 100 km^2 squares in southern England, but only four species reach northern Scotland. The preponderance of dragonfly species in southern England can be related to high temperatures in April. Those few species which have a southern boundary of their ranges in northern areas will become endangered. Montane species are particularly at risk, because their move to higher altitudes may not be matched by the extent of their montane habitats (Peters & Darling, 1985). The change in distribution of species will be greatly influenced by the availability of suitable habitat, any barriers to movement, and the dispersal powers of the species. The most important natural barrier to invertebrate distribution is the North Sea and English Channel: 54 species of breeding butterfly occur in mainland Britain and in Ireland only 25 species, but in NW France, Belgium and Holland there are 92 species (Watt et al., 1990). Within Britain, the current fragmentation of habitat is likely to be significant in slowing changes in distribution. Many species of conservation interest are virtually restricted to nature reserves or Sites of Special Scientific Interest (S.S.S.I.), and the present intensively farmed areas or urban developments present insuperable barriers to movement. However, these barriers are less important to species that disperse long distances (e.g. migrant insects or birds, (Marquiss & Newton, 1990)). Hence, plant distributions are likely to change more slowly than faunal distributions, and some insects may be good indicators of climate change. Moreover, within the geographical range of any species, there are often considerable differences in behaviour, morphology (e.g. body size, colouration) and physiology, which may be sensitive indicators of climate change.

It is highly unlikely that the projected climate changes will result in extinctions of species of soil organisms, except possibly in the case of obligate symbionts where the plant fails to survive. Most components of the soil biotic community have wide ranges of tolerance of temperature and moisture (Whitford, 1992). Further, the short life cycles of most of these organisms should permit genetic adaptation. Climate change may cause shifts in the relative abundance or activity of species which may affect ecosystem processes, such as decomposition and mineralisation. For example, dryness may cause nematode abundance to drop, thereby decreasing how efficiently the soil biota can decompose organic material (Whitford, 1992).

1.5.5 Other effects of climate change

a) Soils

Changes in climate will result in a variety of changes in soil processes including effects on hydrological pathways, decomposition processes and mineral weathering. The responses will vary between soils, depending on the nature of the soil and the previous climate. For example, the free-draining soils in the south and east of the UK will change towards those of the warm temperate and Mediterranean areas. In contrast, an increase in temperature will have very little effect on a heavily waterlogged raw peat soil in the uplands of the UK (Ineson & Stevens, 1990).

b) Coastal habitats

Finally, sea-level is predicted to rise between 0.5 and 3.5 m in the next century and tidal amplitude and storm surges are also likely to change. This would result in increased coastal erosion, particularly in areas with softer rocks, and irreparable damage to salt marshes and mudflats (Boorman, 1990) and associated bird populations (Marquiss & Newton, 1990) and agricultural lands (Parry, 1992).

1.5.6 Resume

A decade ago, the notion that man could warm the earth by producing greenhouse gases was treated with some scepticism, despite the considered opinion of many scientists over 20 years and CO_2 record from Mauna Loa. Today, most scientists accept that some warming will probably occur. However, the extent and rate of global warming and its effects on

regional climates are uncertain. Nevertheless, the likely impacts must be considered to develop knowledge that may be needed in 20-30 years' time. It is also necessary to consider action that can mitigate or exploit potential effects and this is covered in the final chapter.