

## Chapter 6 Vegetation and microclimate

Having clearly defined microclimate in Chapter 2, the present chapter describes in detail the relationship (i.e. effect of) between vegetation structure and microclimate. It starts at the most basic level considering the microclimates of individual leaves (or other plant structures), then progresses to the more gross effects of vegetation cover (e.g. crops, grass) on microclimate. Following a broad description of the general effects of vegetation on microclimate, the separate effects of grassland, heathland and forest cover, which are most relevant in terms of potential effects of climate change are described. Forests are included, since they show very clear effects of vegetation structure on microclimate.

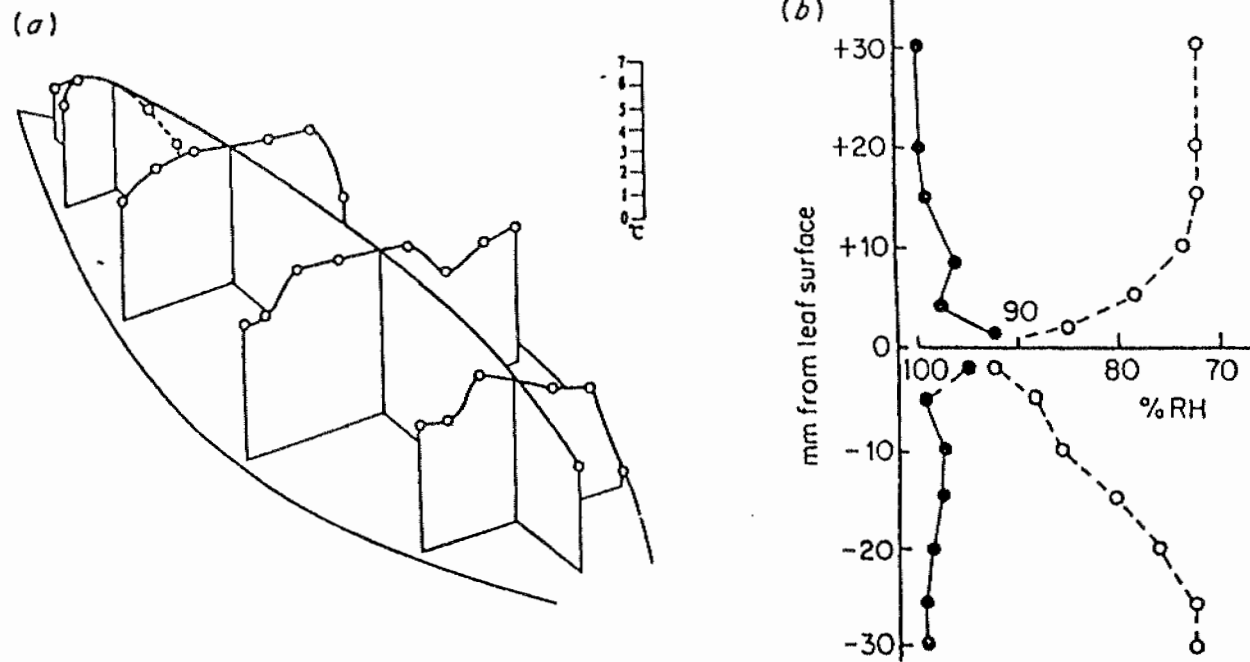
### 6.1 The microclimate of plant surfaces

#### 6.1.1 Leaf surfaces

All plant surfaces have microclimates and develop a boundary of relatively still air, where winds have little effect and where temperature and humidity can be markedly different from ambient. The centre of a leaf commonly has a greater 'temperature excess' (above ambient) than the leaf margin (Figure 3 (a)). Upper leaf surfaces are warmer and lower surfaces cooler during daylight (Willmer, 1986). Leaf temperatures give an insight into the water relations of the plant. Furthermore, the leaf is the habitat of insects, fungi, lichens, mosses and in the tropics even higher plants that live inside or on the surface of the leaf: the phyllosphere (Ruinen, 1961). Willmer (1982a) examined the humidity profile around a cabbage leaf (Figure 3 (b)) and found a microclimatic zone extending at least 10 mm above the leaf upper surface, and a humid zone up to 25 mm deeper under the lower surface during the day. Plant surfaces also include flowers, which by virtue of their shapes can have very specialized microclimates.

#### 6.1.2 Leaf size

Clearly microclimates vary between plants and these may depend on various features of their leaves, which may vary with habitat, plant species and leaf age (Givnish, 1979). The most obvious of these is leaf 'size' which affects temperature and transpiration. The temperature over a leaf is usually lower towards the edges because air mixes more rapidly around the margins so that temperature gradients are always disturbed. Therefore, larger leaves generally show greater temperature excesses (Willmer, 1986) and must transpire strongly to avoid lethal temperatures (Stoutjesdijk &



**Figure 3.** Profiles of microclimate around leaf surfaces  
 (a) The temperature excess recorded above a Canna leaf (from Raschke, 1956)  
 (b) Humidity profiles above and below leaves of Brassica oleracea (cabbage)  
 at 14.00 (o) and 20.00 (●) in summer (from Willmer, 1982b)

Barkman, 1992). In other words, big leaves become hotter in the sun than small leaves, which increases transpiration. However, big leaves also have a thicker boundary layer and a smaller edge effect, both of which reduce transpiration (Gates, 1980). Which of the opposite effects outbalances the other, depends of the diffusion resistance of the leaf interior (Stoutjesdijk & Barkman, 1992). Generally, larger leaf sizes occur in warm, low radiation environments (Parkhurst & Loucks, 1972) and in shade leaves (Barkman, 1988a) but this also depends on soil fertility and moisture status.

### 6.1.3 Leaf shape

As for leaf 'shape', perhaps the most important aspect is the degree of dissection of the margin. Leaves with highly dissected forms develop much lower temperature excesses for a given size (Willmer, 1986) and are therefore selected for in plant species exposed to high radiation (Givnish & Vermeij, 1976). However, some variations in form, such as the spines on holly leaves or mimicry, are better explained in terms of anti-herbivore defence (Mooney & Gulmon, 1982). Brown and Lawton (1991) state that there are at least six ways in which herbivores have influenced the evolution of leaf size and shape, particularly morphologies that differ from those dictated by physiological and biomechanical constraints acting on plants. They are mimicry, not only of leaves but of other plant species and also grazed leaves and inanimate objects; crypsis; physical barriers to being eaten; interspecific differences in leaf morphology to reduce recognition by herbivores; very small or highly divided and dissected leaves that reduce feeding efficiency; and different adult and juvenile foliages. Leaf 'thickness' affects the thermal capacity of leaves and hence their ability to retain heat. A thick leaf may allow much greater temperature differences between upper and lower leaf surfaces than would be possible for a thin leaf (Stoutjesdijk & Barkman, 1992). Shade leaves are generally thinner.

### 6.1.4 Leaf reflectance

Another important aspect is the 'reflectance' of the leaf surface which is compounded by its colour, hairiness (Billings & Morris, 1951) and other surface roughnesses and shine as determined by surface waxes (Mulroy, 1979). Reflectance values are predictably related to the perceived colour, being higher for yellow-green and pale leaves, and lower for the deeper greens and blue-greens. Lower leaf surfaces are always a few per cent more reflective than upper surfaces, and hairy surfaces are highly reflective with values often well over 30%. Seasonal changes in reflectance may occur. For the drought-deciduous desert shrub *Encelia farinosa*, Ehleringer and Bjorkman (1978) found a decrease in leaf absorbance

associated with an increase in the density and thickness of pubescence. Paradoxically, higher reflectance leaves generally have higher temperature excesses though this does not apply to higher reflectance due to hairiness. Presumably, this is due to the high reflectance at both surfaces and high transmittance of radiation through the leaf. Highly reflective leaves also warm and cool more slowly. This is particularly the case for hairy leaves, because their trichomes trap a stagnant layer of air which insulates against temperature change (Stoutjesdijk & Barkman, 1992). Leaf 'texture' may affect reflectance, but can also affect the depth of the boundary layer when wind velocities are low. Texture and roughness may also determine wettability, thus affecting dew formation and precipitation run-off which will in turn greatly affect humidity conditions round the leaf.

#### 6.1.5 Leaf orientation

Apart from the leaf's size, shape, colour and texture, an external variable that will affect its microclimate is of course its 'site' which includes both 'height' above ground and aspect or 'orientation'. Height will affect the balance of direct radiation from above and reflected radiation from the ground, and will also affect how much disturbance from winds the leaf is exposed to. Orientation (or 'inclination') will affect the angle of the leaf to the sun, and hence the heating effect at its surface. Horizontal leaves (i.e. low inclination) catch a great deal of light. They therefore predominate in places with little light, where there is much shade or a short growing season. In Dutch grasslands, the tall grasses usually have leaves with a high inclination while species with more horizontal leaves, especially rosette plants e.g. *Bellis perennis* (daisy), all occur in the lower layers. This also holds for woodlands: in an alder carr in the Netherlands the average inclination in the canopy was  $23^\circ$ , but in the herb layer  $5^\circ$ . Even on the same plant, leaf inclination increases higher up the stem (Stoutjesdijk & Barkman, 1992). Such effects are even more marked in flowers, where corolla angle can be clearly related to corolla temperature in both arctic (Kevan, 1975), tropical (Corbet & Willmer, 1981) and desert (Ehleringer & Forseth, 1980) conditions. Water-stressed plants may have markedly higher temperatures at the leaf surface, but may actually wilt to get out of direct sunlight (Willmer, 1986). A final aspect of orientation concerns the sun-tracking movements of both leaves and flowers, to maintain the structure in the optimal relationship to incident radiation (Ehleringer & Forseth, 1980).

## 6.2 Effects of vegetation cover on microclimate

The effects seen in individual leaves contribute to the microclimates of larger elements of vegetation, e.g. a potato crop (Broadbent, 1950). This creates conditions radically different from those recorded in adjacent Stevenson screens (Broadbent, 1950). The average inclination of canopy leaves determines shading of lower leaves which strongly affects not only their rate of photosynthesis but also their temperature. The temperature, light regime and moisture conditions are modified under the canopy. This is of the utmost importance for bryophytes, lichens, small surface animals and flora and fauna of the upper soil.

For example, measurements show that dense leaf canopies transmit very little radiation in the wavelengths 400-700 nm (PAR) and many times as much radiation in the longer wavelengths, e.g. far-red (Stoutjesdijk, 1972a). This results in a decrease in the red:far-red ratio from the values observed in natural daylight (Holmes & Smith, 1977). If the leaf canopy is dense, as in a well-grown crop of field beans, the ground below the stand is heavily shaded and the microclimatic events take place at the surface defined by the uppermost or outermost leaves. This 'active surface' of the vegetation is a region of steep gradients of temperature and relative humidity (Unwin & Corbet, 1991). The microclimate is modified by all of the above-ground standing crop, both living and dead, green and non-green (e.g. woody stems and branches, flowers and fruits). The vertical and horizontal denseness (or 'inpenetrability') of vegetation as determined by the phytomass and its spatial arrangement (e.g. inclination) is of considerable importance in determining microclimatic patterns (Barkman, 1988b).

Vegetation types vary in their 'albedo' (or reflectance): grassland reflects 15-25% of solar radiation which is about as much as a sandy soil does, but, woodlands reflect only 10-15%, which resembles dark soil. Plants form humus which has a low albedo, a low specific heat by volume and a low conductivity. These factors all contribute to the occurrence of high surface temperatures during the day and low temperatures at night by insulation of the subsoil. Another important factor is the presence of litter whose quantity and quality affects water retention and temperature in the topsoil (Osbornova *et al.*, 1990). The size of the decaying leaves is critical. Large leaves form big air cavities which are cool, moist and rich in CO<sub>2</sub>, whilst small leaves and needles form a loose type of litter which easily dries up.

The change in the intensity, spatial distribution, and quality of solar radiation penetrating vegetation is paralleled to some extent by changes in the movement of air through the canopy. Like radiation, air movement is depleted with depth in the vegetation because of the multitude of obstructions to both sunlight and the wind flow. Air movement within a canopy of vegetation affects, to varying degrees, the growth and development of the plants themselves, pollen transfer and seed dispersal, insect activity, and the dispersal of fungal and bacterial diseases.

### 6.3 Effects of different vegetation types on microclimate

#### 6.3.1 Grasslands

Champness (1950) studied the establishment of timothy grass (*Phleum pratense*) and white clover (*Trifolium repens*) and found that small seedlings growing closer to larger seedlings remained healthy whereas others surrounded by bare soil died. This was attributed to the greater protection afforded to the delicate growing parts. Similarly, Jaksic and Fuentes (1980) found that native perennials in central Chile are more abundant underneath bushes because the microclimate there prevents desiccation. Waterhouse (1950, 1955) studied microclimatological profiles in grass cover and found that the stratification of air temperature is related mainly to the presence and absence of radiation. While sunshine penetrates considerably in the upper region, there is often a considerable fall thereafter and practically no direct insolation at lower levels. The vertical distribution of air temperature in grass found by Waterhouse (1955) is similar to the zonation found by Geiger (1965) in cornfields. However, the depth of penetration of insolation within the canopy will depend upon the height, density and mode of growth of the vegetation concerned and the sun's altitude, all factors which vary seasonally and/or diurnally. Champness (1950) and Waterhouse (1955) showed that the level at which radiation is absorbed is raised as the vegetation becomes taller, so that the temperature is less variable near the ground.

Large differences in structure, height and density occur in grasslands and so the fate of incoming radiation varies greatly (Fliervoet & Werger, 1984, 1985). Using measurements of temperature and saturation deficit Stoutjesdijk and Barkman (1992) classified various Dutch grasslands into four microclimatological types. These were cool-dry, cool-moist, warm-dry and warm-moist grasslands. 'Cool' meant that the temperature in the vegetation was lower than that of the surroundings and was more typical of grasslands with dense 'closed' structure ('warm', the opposite). 'Moist'

meant that the saturation deficit was lower than outside the vegetation and depended more on soil moisture content ('dry', the opposite). Fliervoet and Werger (1985) studied three Dutch Calthion palustris (marsh marigold) communities and found that they varied, as a result of differences in growth season, temperature and wind, in the vertical distribution of biomass and leaf area (LAI), and growth form and leaf size composition. Profiles of decreasing light intensity within the vegetation canopy are related to the vertical distribution of biomass, LAI and leaf inclination. Profiles of temperature and saturation deficit show a similar shape in the different sites which suggests that vegetation structure differs under the influence of the macroclimate so that the resulting vegetation canopies modify the microclimate within the vegetation to become homologous.

In all, but the shortest grass cover, the atmosphere becomes increasingly humid as the ground level is approached. Humidity may be particularly great in the mat of litter which often forms. There is a sudden reduction of windspeed within grass canopies. Waterhouse (1955) stated that a steep gradient of wind speed from zero to 90 or 100 cm/sec might be expected in the region some 40 cm to 15 cm below the upper surface of a stand under a variety of conditions. In alpine meadows and pastures, Cernusa and Seeber (1981) found that, compared with that measured at a surface height of 2 m, windspeed was 50% at the canopy surface and declined to 15-30% in the middle layer of the canopy. Over 50% of the green material was exposed to wind velocities which reach only 10-15% of the values at 2 m.

Only very homogeneous vegetation such as agricultural grassland can be characterised by vertical profiles temperature, humidity, wind and radiation. A more natural grassland shows various forms of horizontal heterogeneity, e.g. tussock structure. Small differences in aspect and strong temperature differences occur between the north and south side of a tussock. Luff (1965) defined a 'tussock' as "a plant which is easily distinguished from the surrounding herbage by the closeness of its leaves and stems, which form a dense tuft, and also by either the accumulation of dense herbage around it, which separates it from the adjacent grass, or by its being elevated on a stool of dead vegetable matter in which soil or silt has accumulated." He studied the morphology and microclimate of Dactylis glomerata (cocksfoot) tussocks which lived for at least 9 years and could be divided into 'immature', 'mature' and decaying stages. The greater density and height of the tussocks combined to reduce the temperature fluctuations in the lower part of the vegetation, in comparison with the intervening grass. These differences between the different types of grass were greatest in clear, warm weather and were reduced in cloudy weather and in winter.

### 6.3.2 Heathlands

The structural changes which occur in heathland vegetation, undergoing cyclical or successional change, profoundly affect the climate near the ground. In turn, the germination and establishment of seedlings beneath the canopy and the occurrence and distribution of many species of animal may be affected. Early work on this topic by Delany (1953) in pioneer communities on the Pebble Bed heathlands in south-east Devon, by Stoutjesdijk (1959) in The Netherlands, and by Gimingham (1972) in Scotland, showed that temperatures were lower and humidity was higher beneath the canopy of the heather plants than in the air above the plants, and on sunny days this difference was greater than on dull days. The canopy restricted air movement, thereby enabling differences in humidity and temperature to build up, but, on windy days, these differences were less, due to greater mixing of the air within the vegetation. The canopy reduced the light reaching the soil surface by 80%, making germination and seedling establishment almost impossible.

On the same Scottish heathland, from which the cyclical processes in the community were described and interpreted, Barclay-Estrup (1971) made a detailed study of the microclimate beneath representative bushes from the four morphological phases. In the 'pioneer' phase, the microclimate was characterized by extremes. At ground level, illumination was high and temperatures were high on days when there was strong insolation (sunlight). In the winter, night temperatures were often low. High saturation deficits were often and both air movement and throughfall and precipitation were at a maximum.

The closed, dense canopy of the 'building' phase profoundly modified this pattern. Illumination was reduced to as much as 2% of the outside, temperatures were generally lower than in any of the other phases, saturation deficits were always low, air movement was negligible and very little precipitation reached the ground level. Changes in the structure of the Calluna canopy were mainly responsible for differences between the building and 'mature' phases. In this latter phase, illumination at the soil surface increased to 20%, temperatures were both higher and lower than in the building phases, but the saturation deficit was still low, and the canopy was still sufficient to considerably restrict air movement and intercepted most precipitation.

The degenerate phase was somewhat similar to the pioneer phase. The microclimate became increasingly extreme, sometimes even exceeding



that in the pioneer phase. Illumination increased up to 57%, the range of temperatures was much greater than in either the building or mature phases, saturation deficits were higher, air movement much more, and the amount of precipitation reaching the ground was similar to that in the pioneer phase. Soil temperatures showed much less variation between the phases, but the highest maxima and lowest minima occurred in the degenerate and pioneer phases.

### 6.3.3 Forests

In principle, the microclimate of a forest is not different from that of the other types of vegetation. Forests give shadow, change the light climate, slow down the wind, make the air moister through evaporation and temper temperature fluctuations. The main difference, though, is in its size relative to the human observer who can walk inside the microclimate and take measurements with classical apparatus. Hence, the oldest measurements are almost 100 years old.

In contrast to many temperate grasslands and heathlands and most tropical vegetation, temperate woodlands are deciduous and their microclimate in winter is different from that in evergreen structures. They form thicker layers of litter and humus, which influence the microclimate near the ground, especially in sunny patches (MacKinney, 1929). Trees can keep a great deal of precipitation in their crowns and the throughfall along stems, branches and openings in the canopy creates an irregular pattern of precipitation on the floor.

Natural forests are heterogeneous because of the mixed tree composition and age, size, and gap structure. Tree species differ in bark roughness, inclination of branches and leaves and leaf size, form and thickness (Barkman, 1988a). Continuous vertical development of branches and leaves creates a unique microclimate. However, most of what we know about the microclimate in forests is based on woodlands with an artificial structure (Chapman *et al.*, 1931; Sparkes & Buell, 1955). For example, in planted woods with a dense canopy and very little understorey there is more wind and exchange of air with air above and outside the wood. This creates an even microclimate with the temperature at 2 m in the wood (where the windspeed was only 12%) only 1.2 °C lower than outside the wood, the vapour pressure 1 mbar higher and the saturation deficit 3.3 mbar lower (Stoutjesdijk & Barkman, 1992). Wind movement inside a forest increases transpiration and evens up temperature differences. Forest structure and the state of the foliage have an important effect on the wind velocity (Olszewski, 1974). Radiation absorption in forests occurs at levels

high above the surface in what is called the 'active surface'. In extremely diverse forest structures, there may be hardly any clear active surface and several temperature maxima may occur.

The fate of precipitation depends on the crown density and especially the density of leaves. Coniferous forests with their narrow leaves keep the rain in the canopy longer longer than broad-leaved forests. Of the rain falling through the crown leaves, some falls directly onto the ground, called the 'throughfall'. Some runs partly down the branches and finally down the tree stems, called the 'stem flow'. The distribution of rain over the forest floor is irregular because different trees have different crown densities.

As sunlight passes through vegetation, it is not only gradually weakened by absorption but its spectral composition changes as well. Chlorophyll has a very specific absorption spectrum with strongest absorption of wavelengths  $< 700$  nm and weakest in the near infra-red ( $> 700$  nm). Radiation transmitted through the leaves is rich in dark red and infra-red, and relatively rich in green light (Zavitovski, 1982). This effect becomes stronger as it passes through more leaves. One leaf transmits 50% of the infra-red and 10% of the short wave lengths, but for two leaves these figures drop to 25% and 1% respectively (Stoutjesdijk & Barkman, 1992). Coombe (1957) found that deciduous woodland is a much more highly selective filter than coniferous (evergreen) woodland. Stoutjesdijk (1972b) found that the red: far-red ratio was higher for tropical rainforests than deciduous woodlands.

#### 6.3.4 Vegetation edges and gaps

Small-scale variation in vegetation structure and in microclimate occur especially in semi-natural vegetation. Such horizontal variation is one of the differences between natural vegetation and stands of an agricultural crop. An important aspect of horizontal variation not yet discussed fully is the effect of sharp boundaries, both natural and artificial, between adjoining tall and low vegetation.

When the sky is bright the shade light received at the north side of a deciduous hedge or strip of scrub contains much blue and far-red radiation and little near red. The light intensity is relatively high but net radiation may be zero or slightly negative because of the strong long-wave radiation loss to the 'cold' bright sky. Dew persists in these situations and surface temperatures are often 6-8 °C below ambient air temperature. This microclimate was termed the 'open shade' by Stoutjesdijk (1974). It may

exhibit small-scale pattern especially at low sun elevations, as soon as areas with low vegetation are found in taller structures. Open gaps in between grass tussocks remain cool and covered with dew. In winter, the open shade may be more pronounced and, because of the low elevations of the sun, more extended as well. The counterpart of the open shade is found along the southern edges of woods, hedges and rock walls. In these 'warm fringes' total radiation may be about equal, windspeed often lower, and the vegetation drier than that found in open fields. So far we have discussed forest edges with a sharp, usually anthropogenic transition to lower vegetation. In cases where there is a more gradual transition between forest and grassland with shrubs and forbs ('fringe communities'), the microclimate is transitional as well.

In natural forests, open areas are an essential part of the vegetation structure with their own microclimate. This is important for forestry and nature conservation since many trees regenerate in gaps and many plants and animals are bound to such open places. Microclimatic conditions at the centre of a gap are a function of gap shape, orientation, and size (in relation to the height of the surrounding forest) which determine the daily duration of direct insolation (Denslow, 1980). In the case of large open places such as forest meadows, large clear-cuttings and storm-fellings, a typical warm microclimate arises at the northern edge of the open place and a typical cool moist open shade climate on the south side. In regions with prevailing westerly winds, the west side of gaps will be sheltered from wind and will receive sun only in the morning, while the east side receives afternoon sun. Very small open areas show a microclimate that deviates little from that in the forest, mainly in that there is somewhat more diffuse light from the sky. In temperate regions, areas with a diameter ( $d$ ) of at most 70% of the height ( $h$ ) of the surrounding trees will not receive any direct solar radiation and areas with a  $d/h$  ratio of 1 will receive very little. As a result temperatures do not differ from those in the forest. Gaps with a  $d/h$  ratio of 1.5 to 2 are microclimatologically the most deviating ones, more than 5 °C higher than in the forest. At night, an open place functions like a frost pocket with no wind to carry the cold away (Hough, 1945). Because rain comes in at an oblique angle, tree crowns catch part of the rain from a gap and in small gaps ( $d/h < 1$ ) precipitation is less than in the open field. Absolute humidity in a gap is higher than in the open field because of the transpiration from the surrounding trees. At night, dew is formed in the gaps, though less than in the open, at the edges less than in the centre, and in large gaps more than in small ones.