

## a) Plants

Vegetation patterns on various scales can largely be interpreted in terms of the effects of microclimate, as modified by vegetation structure and other factors, on plant development. These effects are particularly important in the early stages of development, i.e. seedling germination and establishment.

### i) Established vegetation

Pronounced differences in vegetation can be detected between neighbouring north- and south-facing slopes, correlated with differences in soil temperature and moisture, frost and solar irradiance. The climate of plant surfaces may differ considerably from that of the air above, depending on structural attributes of the vegetation. Short vegetation (i.e. herbaceous) is aerodynamically much smoother than tall vegetation (i.e. woody) and mixing with the atmosphere is much less efficient. The epiclimate differs much more from the climate of the air above. Because vertical gradients are less pronounced near the forest floor, initial growth may be unimportant. Here, physiological and morphological adaptations are related to the 'tolerance' (i.e. woodland plants) rather than 'avoidance' (i.e. grassland plants) of shade. This explains the transition from forests to dwarf shrubs at the treeline. On a finer scale, within habitats, (e.g. grasslands) microclimate clearly determines leaf size, consistency and inclination.

### ii) Seedling regeneration

The distribution and abundance of plants is largely determined by the ecological tolerances of the early stages of development, namely germination and seedling establishment. Effects of climate change on these phases of the life-cycle will be the most crucial in determining patterns in plant communities. Regeneration is crucially dependent on the presence of competition-free 'gaps' which differ markedly from closed vegetation in terms of light, temperature, water supply, litter etc. Gaps varying in size, shape, slope, aspect, timing and persistence may differentially favour species according to their germination characteristics. Seeds of some species may only germinate once they have been exposed to certain combinations of fluctuating temperature, moisture levels and light in terms of duration or quality and surface microtopography. The response may depend on the size, shape and orientation of the seeds and crucially determines the overall ecology of the species. Small-seeded grassland species often have a requirement for fluctuating temperatures which acts as

a gap- and depth-sensing mechanism. This prevents them from germinating in a dense sward or at depths too great for emergence, whereas larger-seeded species can emerge in dense cover and from greater depths. These germination requirements, which are often very precise, may not be met if the climate changes radically. For example, more seeds may germinate at depths unsuitable for seedling emergence. The response may differ between grasslands and heathlands.

The early stages of seedling growth have high mortality rates due to abiotic factors such as shade, drought, burial and biotic factors such as competition, predation and disease. Within low vegetation, small differences in height are associated with large changes in the intensity, direction and quality of radiation, and seedling establishment may depend on height, aspect or inclination of the first leaves produced by a seedling. This may depend crucially on life-history traits of species. Plants from closed vegetation tend to have larger seeds than those from open habitats, because large food reserves are required for seedling establishment in shade. Greatest mortality occurs during periods favourable to growth, i.e. spring, and so smaller-seeded species are autumn germinators. Small-seeded species may be more prone to drought but are more easily buried and may survive unfavourable periods in the dormant seed bank. In some cases, the presence of established plants or a bryophyte layer in the vicinity of a seedling increases the chances of survival.

#### b) Invertebrates

The large surface area: volume ratio of small animals means that the conservation of water is the prime physiological problem of their existence. Most terrestrial invertebrates spend most, if not all, of their time in a damp or humid environment. These 'cryptozoic animals' include worms, slugs and primitive arthropods such as woodlice and spring-tails. Lacking an effective waterproof covering, they rapidly lose water by transpiration, and are therefore generally active at night, spending the day in sheltered microhabitats. More highly evolved insects and spiders possess a thin cuticle which is impervious to water vapour and reduces transpiration to a minimum. Their distribution is less severely limited by microclimatic factors.

The effects of microclimate on ecological systems can be understood in terms of physiological effects on thermal and water balance. These are mediated through morphological and physiological factors which help to explain differences in ecology and behaviour.

### i) Thermal balance

Behavioural mechanisms allow insects to maintain body temperature by finding and using more equable microenvironments in which they may heat up or cool down as required. Some large insects, (e.g. beetles, butterflies, Orthoptera) show considerable powers of endothermic regulation. The mechanisms of shivering, to achieve warm-up and blood-shunting to permit cooling, may be directly triggered by microclimate as perceived by the insect's receptors. The various sources of heat gain and loss for an insect are influenced in turn by several features of the animal itself, namely, size, shape and surface area, colour and surface texture and its orientation or posture, which may clearly vary between and within species and during the life-cycle of an individual. This in turn influences its microclimatic preferences.

Larger forms may tolerate less stable environments and intermittently higher radiation because they change their body temperature more slowly which 'smoothes out' some of the variation. They may also become active under cooler conditions with limited solar radiation, because their temperature excess is greater. Patterns of activity at a particular site can thus be correlated with the size of insects as it relates to their temperature requirements. Flower-feeding insects may visit at times and in places where temperatures around the flowers are suitable, rather than visiting at times of maximum nectar or pollen rewards. Surface features, (e.g colour) may be important. Insects may be insulated by bristles, hairs or scales which trap a boundary layer of air.

Changes in posture are very important for long-legged insects which live on very hot surfaces and exhibit 'stilting' to reach a favourable microclimate, e.g. grasshoppers and certain beetles. Butterflies may 'bask' with wings outspread to maximize radiative gain or close their wings to reduce heat uptake. Insects may alter their radiative balance by 'orientation', varying the surface area exposed to the sun as in long-bodied insects, such as Odonata and Orthoptera. At such extreme temperatures, insects may be forced to relocate either by burrowing to reach more equable conditions or 'shuttling' between sunny-and-shady locations, as observed for beetles.

### ii) Water balance

Insects regulate this by internal metabolic or physiological processes and by behaviour appropriately coordinated with their environment. In general, they must seek rather cool and very moist conditions to limit

losses of water. Larger, more compact insects with a lower surface area: volume ratio are at an advantage, but clearly cannot exploit small humid zones. However, the most important factor is the permeability of exposed cuticular surfaces which varies considerably with environmental conditions, e.g. temperature, humidity. Most heat-avoiding strategies take insects into cooler, more humid zones where water loss will be reduced, whether stiling, burrowing or shade-seeking. Specific techniques which affect water balance include spiracle opening and closing, or changes in the ventilation rate, the extrusion of salivary or excretory fluids and water uptake.

### iii) Wind

Air movements may influence the distribution of terrestrial arthropods, such as locusts, aphids and spiders. High wind speeds may limit aeronautic activity and cause small flying insects to accumulate in the sheltered zones near to hedgerows or other 'windbreaks'. Grasses with a tussock growth form provide shelter for invertebrates in winter or during adverse weather, while grassy field-edges with a well-developed litter layer provide important overwintering sites.

## 10.2 Predicted effects of climate change

The major predictions of climate simulation models are a general warming of the earth's surface with stronger warming at higher latitudes and in winter. The projected rate of warming is faster than past global warming and is likely to increase global rainfall due to greater evaporation from the sea and land. Moreover, large regional variations and 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.

### 10.2.1 General vegetation changes

The spatial pattern in the vegetation of the British Isles is often strongly correlated with climatic variables (section 1.2). However, the scale of resolution of national distribution maps does not allow one to distinguish between patterns imposed by climate and those more strongly influenced by land use or local habitat conditions. Clearer evidence is provided by 'aspect preferences' for north- or south-facing slopes (i.e. correlations on a local scale) and detailed field and laboratory investigations of the relationship between plants and climatic factors. A likely consequence of climate change

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 the retreat of upland and montane species (section 1.5). If winters become milder, the lack of suitable frosts may be an important factor limiting scrub invasion, and thereby successional communities of plants and insects, in grasslands and heathlands. The buds of many woody perennials need to be chilled in winter to release dormancy. If the buds are not fully chilled, they 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.

a) The direction of change

Grime and Callaghan (1988) attempted to devise predictions of the impact of climate change on the vegetation of the British Isles. These were based on a) the long tradition of climate recording and the study of the distribution of plant species (Perring & Walters, 1976), many of which have sharply-defined distributions imposed by climate (Piggott, 1968; Piggott & Huntley, 1981) and b) additional insights provided by data relating to the seasonal patterns of growth (Al-Mufti *et al.*, 1977; Grime & Mowforth, 1982; Grime *et al.*, 1985), flowering, seed dormancy (Thompson & Grime, 1979), and germination (Grime *et al.*, 1981; Hillier, 1984) in a wide range of native species (Grime *et al.*, 1988). They made the following predictions about the 'direction' of vegetation changes initiated by climate change:

1. In southern England, particularly on dry soils, the growing season will shift significantly towards the autumn, winter and spring, with a quiescent phase often occurring in summer. In northern Britain, there will be a lengthening of the summer growing season.
2. Conspicuous changes will occur in the relative abundance of various constituents in familiar vegetation types. These will be most obvious in southern Britain. They will vary locally according to habitat factors and vegetation management and are predictable from phenological data. In general, grasses and geophytes with high nuclear DNA amounts will remain important in drier habitats, but where moisture supply is sufficient to sustain summer growth, a progressive trend towards species with low DNA amounts seems likely. In southern Britain, bryophytes may be expected to decline in abundance at well-drained sites in grassland, scrub and woodland. The current bimodal seasonality in bryophyte growth (autumn and spring) in grasslands and woodland is predicted to be replaced at many southern sites by a unimodal (winter) pattern and lichens will become more abundant locally.

3. Warmer conditions and lengthening of the summer will promote a generally higher level of flowering, seed and spore production and a greater incidence of insect cross-pollination in British vegetation. This may have profound long-term effects especially in northern Britain and at higher latitudes where effective sexual reproduction is currently a rare event in many populations.

4. Many of the trees, shrubs and herbaceous plants (e.g. Tilia cordata (small-leaved lime), Cirsium acaule (dwarf thistle)) which currently reach their northern limit in England or Southern Scotland will begin to expand northwards. This will mainly arise through increased seed viability, particularly in exceptionally warm years, but other factors will be important in particular species, e.g. climate warming will lead to an expansion in the area of desiccated open vegetation available for colonisation by ephemerals.

5. Species currently restricted to south-facing slopes in northern Britain will begin to colonise other aspects.

6. Expansion to higher altitudes will begin to occur in many lowland species. Across Britain, upland plants which favour cool, moist conditions (i.e. the post-Ice Age flora of alpine plants and mosses) may face extinction since they will be gradually pushed out by newcomers from the south and east. Their plight will be worsened as warmer weather encourages arable farmers to spread northward, eating up open land. Two such species, Jacob's ladder (Polemonium caeruleum) and mossy saxifrage (Saxifraga hypnoides) have already begun declining over the recent hot summers.

7. Plants with a northern distribution in Europe may be expected to retreat from the southern extremities of their ranges in Britain. This is likely to be most evident in shallow-rooted, calcifuge species (e.g. Deschampsia flexuosa (wavy hair grass), Galium saxatile (heath bedstraw)) and will be a discontinuous process involving vegetation and soil changes, accelerated by drought mortalities, fire and soil erosion in exceptionally warm years.

8. For the reasons described under 7, northern species may retreat from lower altitudes, at localities in southern Britain and at more northerly sites there will be a tendency for populations to show reduced vigour on south-facing slopes.

9. The advent of a warmer climate will create the obvious possibility of the incursion into Britain of plants which flourish under Mediterranean conditions. Many of these plants have already established 'toe-holds' in the south or survive locally in coastal or urban areas. The lizard orchid (Himantoglossum hircinum), which can take 20 years to germinate and flower, is abundant in France but one of Britain's rarest plants. However, a recent article in the Guardian revealed that within 6 years the number of flowering plants had tripled from 962 to 3,000, and had spread from isolated pockets in Kent and Cambridgeshire to establish new colonies in

Dorset and Somerset. Similarly, the grass-bearded fescue (*Festuca ambigua*), whose world population was previously limited to south-east England, has recently appeared in Devon and mid-Wales and numbers have exploded from a few hundred to around 10,000. However, the scale of invasion will depend crucially upon future policies of land-use in Britain (see below).

10. Climate change, operating in isolation from other modifying factors, is unlikely to lead to widespread extinctions of common species from the British Flora. Nevertheless, many rare plants may become even more precarious through their limited abilities for genetic change or effective migration. Particularly threatened are species in which small populations now occupy cool, continuously-damp refugia on isolated steep north-facing slopes.

b) The rate of change

Grime and Callaghan (1988) also make predictions about the 'rate' of vegetation change induced by climate change. These include inconspicuous and gradual forcing, together with occasional more catastrophic effects in exceptionally hot, dry years. The former will involve *in situ* shifts in the relative abundance of plants already present within communities, but movement of vegetation boundaries and species excursions and extinctions will be much more dependent on the latter. This is because a high proportion of the natural and semi-natural vegetation of the British Isles consists of a closed cover of perennial plants in which colonisation by seeds is a rare and hazardous process. Establishment and spread of thermophilous species will be much more likely following years of drought in which death and debilitation of established plants exposes the soil surface and creates opportunities for seedling establishment. Years which are sufficiently warm to create an unusual number of vegetation gaps will also, in many southern species, produce exceptional crops of viable seed. The probable coincidence of these two phenomena is central to our firm prediction that vegetation changes will proceed in 'spurts' and that extreme years will be of key significance.

The rate at which vegetation responds to changing climate will also depend upon habitat conditions, management and, most crucial of all, the life-histories and reproductive biology of the constituent species. Predictions often assume that there will be no major impediments to species dispersal. Furthermore, large differences exist between species in their capacities to disperse and expand their geographical limits (Salisbury, 1942; van der Pijl, 1982). Life span is a particularly important predictor of the rate of vegetation change. Where regular disturbance by cultural

practices maintains communities of annuals or short-lived perennials (i.e. ruderal or ephemeral species), the dynamic nature of the vegetation will allow close tracking of climate fluctuations by alterations in species and genotypic composition. In woodlands, scrub, heathland and permanent grasslands, the longer life-spans of individuals and the slow turnover of the populations (especially for stress-tolerant species) is likely to delay the response of the vegetation to climate change. Since, vegetation responses will occur most swiftly in circumstances of frequent habitat disturbance and rapid population turnover, it is important to take into account the potential modifying effect of future policies in land-use and vegetation management. The revolutionary change in land use since 1930 has caused rapid and ongoing changes in floristic composition (Hodgson, 1986a, b). Particularly in lowland England, there has been a major expansion in the range and abundance of fast-growing perennials with high fecundity and prolific ephemerals in response to both eutrophication (i.e. competition) and disturbance. The general conclusion which follows from this analysis is that current land-use policies are conducive to rapid floristic responses to climate change and will encourage invasion by thermophilous species with 'weedy' characteristics (i.e. fast-growing, fecund)(Grime and Callaghan, 1988).

### 10.2.2 Changes in grassland and heathland habitats

#### a) Introduction

Certain generalisations can be made about what will happen to certain limestone grassland and heathland habitats. The specific examples chosen are the Brachypodium pinnatum/Bromus erectus grasslands (Rodwell, 1990) and lowland heathlands (Webb, 1986) in the south of England. Plant species vary in their optimum growth temperatures: widespread grasses like sheep's fescue (Festuca ovina) and perennial rye grass (Lolium perenne) have lower optima (18.7 and 19.8 °C respectively) than species with predominantly south-eastern distributions, such as upright brome (Bromus erectus) and tor grass (Brachypodium pinnatum) (20.2 and 20.9 °C respectively). The latter species have the potential for increased yield under warmer summer temperatures, while other species may be less favoured. If the climate warms up, Brachypodium pinnatum and Bromus erectus, which have predominantly southern distributions, would be expected to spread northwards so that many areas where these species are currently absent may shift towards this calcareous grassland type.

In Britain, there is a strong correlation between the amount of nuclear DNA and the time of year when a plant grows (Grime &



Mowforth, 1982). High DNA content is associated with a large cell size and occurs in species which grow in late winter or early spring, (e.g. native grasses and bulb plants (geophytes)). Conversely, plants with small cells and low DNA content tend to delay growth until early summer. This information can be used to predict the responses of plant species to increased temperature. For example, Grime (1983) conducted growth-room experiments comparing the resumption of leaf growth after drought in Brachypodium pinnatum (2C DNA 2.3 pg (i.e. per nucleus)) and Bromus erectus (22.6 pg), two perennial grasses of similar distribution in Britain but widely contrasted in nuclear DNA content. In B. erectus, the end of the drought period was followed by a surge in leaf growth which exceeded that of undroughted control plants at both warm and cool temperatures. In contrast, leaf growth of B. pinnatum remained well below that of undroughted control plants during the recovery period. Models forecast that episodes of drought may become a more regular, seasonal feature of the British climate. Differences between species in drought tolerances may be a major determinant of changes in plant species composition. Species with a high nuclear DNA content which grow earlier in the year (and avoid summer droughts) may be at a considerable advantage especially in the south of England. Drought is probably the greatest threat to heathlands since heather plants are shallow-rooted (Tinhout & Werger, 1988) and the most diverse plant communities generally occur on the wetter soils (Webb, 1986). Drought is not such a severe threat to the flora of calcareous grasslands, since many of the species are adapted to periodic desiccation, e.g. by having dormant seeds or a well-developed tap-root.

#### b) Autecological information

Piggott (1984) believed that "the lack of an accepted classification of British vegetation has retarded the development of ecology and deprived nature conservation of an essential tool". One approach to remedy this has been to compile detailed biographies of important species, i.e. 'Biological Floras', although these lack the simplicity and generality required by vegetation managers. A more functional approach involves the recognition of major plant strategies and their role in vegetation processes (Grime, 1979). As a result of such research, autecological information is now available on the key ecological attributes, set out in tabular form, of 281 of the commonest species of inland Britain (Grime *et al.*, 1988). These data provide a unique opportunity, for both conservation management and associated research, to predict the effects of relevant ecological processes on vegetation.

This information allows certain predictions to be made about the effects of climate change on limestone grasslands and lowland heathlands and their constituent plant species. These are based on both general ecological attributes (Appendix 1), and those of the established (Appendix 2) and regenerative phases (Appendix 3) of 20 plant species in each of the two habitat types. These data are derived from tables in Grime *et al.* (1988) (mentioned above), and are restricted to attributes that are of clear relevance to climate change or illustrate key differences in ecology between the habitats or species.

#### i) General

Certain generalisations may be made about the 'direction' of vegetation change as a result of climate change. The distribution in northern Europe of several species of limestone grasslands is largely restricted to southern areas of Britain, whereas heathland species are largely restricted to northern Britain, Scandinavia and central regions. The former would be expected to spread northwards under global warming, whereas the distribution of heathland species might become increasingly restricted to northern areas (Appendix 1). Limestone grassland species are largely calcicoles occurring on dry basic soils but have wide ranges of pH tolerance. By contrast, heathland species are all calcifuges strongly restricted and preferring wet, acidic soils, i.e. they have a narrow range of pH tolerance. The shortage of land with a suitable soil type is an additional factor which strongly limits the future extent of heathlands, particularly in southern England.

#### ii) Established plants

In the established phase (Appendix 2), most of the grassland species are leafy, evergreens with wide ranging life-history strategies (i.e. CSR strategists) that flower early in the season (i.e. May-June) but for an extended period (i.e. 3-4 months), e.g. Sanguisorba minor (salad burnet), Viola hirta (hairy violet), Hieracium pilosella (mouse ear chickweed). By contrast, many heathland species are semi-rosette, largely aestival (duration of canopy spring to autumn) stress-tolerators which flower late in the season (i.e. June-July) and for a restricted period (i.e. 2-3 months) e.g. Calluna vulgaris (heather), Erica tetralix (cross-leaved heath), Juncus acutiflorus (sharp flowered rush). The lower and later growing species (e.g. Deschampsia flexuosa (wavy hair-grass), Molinia caerulea (purple moor-grass) and Potentilla erecta (creeping cinquefoil)) may be more prone to summer drought and readily outcompeted by earlier and taller growing (e.g. grassland) species, particularly if the growing season shifts

to autumn-winter-spring as predicted by Grime and Callaghan (1988). The later and more restricted flowering phenology of heathland species may mean that seed production is more vulnerable to periodic summer droughts. This may be particularly significant in view of the generally lower seed output of stress-tolerators.

### iii) Seedling regeneration

In the regenerative phase (Appendix 3), the seeds of many grassland species are generally heavier (>1 mg), are dispersed in an unspecialized manner and require drying or scarification to break dormancy. By contrast, the seeds of heathland species are generally lighter, more are dispersed by wind and animals (i.e. specialised dispersal) and are capable of immediate germination. The larger seed size of grassland plants indicates that they may germinate in smaller gaps (i.e. taller and denser vegetation cover) than heathland species. This may be crucial if climate change results in increased rates of production, especially where soil fertility permits rapid vegetative growth and/or regular disturbance is absent. Summer droughts may increase the germination of grassland species, whose seeds have a drying requirement. The more specialized dispersal requirements of some heathland plants may restrict their spread following climate change. The unspecialized dispersal of grassland species means that they have more versatility. Indeed, certain types of disturbance may encourage the spread of grassland species into heathlands, a process which would increase under global warming.

### c) Changes in individual plant species

Initially, climate change effects might be manifested as changes in remaining patches of habitat. Certain predictions be made regarding changes in the relative importance of species within existing plant communities. In both grasslands and heathlands, evergreen species might grow more in the winter and this would give them a competitive advantage over aestival species. Early flowering species may also increase if drought adversely affects later flowering species. Species whose seeds require drying in order to germinate may increase, whilst those that require chilling may decrease. However, the relative importance of these effects may differ between the two habitats.

#### i) Grasslands

In limestone grasslands, species which are characteristically restricted to southern areas might be expected to increase in abundance

(e.g. Hypericum perforatum (perforate St. John's wort), Sanguisorba minor (salad burnet). Species with a wider range of pH tolerance (e.g. Galium verum (lady's bedstraw), Vicia sativa (common vetch)) which occur on neutral as well as calcareous soils, will be able to spread northwards more easily than strict calcicoles, since more sites will be suitable. The shift in growing season and summer drought might differentially favour species which grow and flower earlier in the year (e.g. Medicago lupulina (black medick), Veronica chamaedrys (germander speedwell), Viola hirta (hairy violet)) at the expense of later flowering species (e.g. Clinopodium vulgare (wild basil), Hypericum hirsutum (hairy St. John's wort)). Germination of species with seeds that require chilling in order to germinate (e.g. Linum catharticum (purging flax), Viola hirta (hairy violet)) may be adversely affected, whilst species with seeds that require drying in order to germinate (e.g. Clinopodium vulgare (wild basil), Sanguisorba minor (salad burnet)) may be expected to increase.

#### ii) Heathlands

Drought is probably the greatest threat to heathland species. If existing heathland soils become drier, species which currently occur on drier, less acidic soils and have wider tolerances (e.g. Hypericum pulchrum (slender St. John's wort), Juncus acutiflorus (sharp-flowered rush), Molinia caerulea (purple moor grass)) will be able to spread more easily than highly calcifuge species (e.g. Dactylorhiza maculata (heath spotted orchid), Ulex europaeus (gorse), Vaccinium myrtillus (bilberry)), which may become increasingly restricted to waterlogged or other acidic sites. Drought may also adversely affect species that flower later in the summer (e.g. Calluna vulgaris, Teucrium scorodonia (wood sage)) thereby giving the competitive advantage to early flowering species (e.g. Betula spp. (birch), Polygala serpyllifolia (heath milkwort), Rumex acetosella (sheep's sorrel)). As for germination requirements, species with seeds that require drying may increase (e.g. Hypericum pulchrum, Rumex acetosella, Senecio sylvaticus (heath groundsel)), whilst those with seeds that require chilling may decrease.

#### d) Changes at the habitat level

Changes in the distribution of grasslands and heathlands would be expected to result from increased warming and drought. Limestone grassland species would be expected to spread northwards and occupy other habitats, particularly in view of the fact that they have early phenologies of growth (i.e. evergreen) and flowering. Heathland species, by contrast, with their predominantly northern distribution in Britain and Scandinavia and

central regions are more prone to extinction as the climate becomes more Mediterranean. They may be more prone to the effects of summer drought due to the fact that they grow and flower later (i.e. aestival) in the year and are shallow-rooted. Their dependence on animal dispersal is a factor which may limit their dispersal, if suitable dispersers are absent. The synchronicity of plants and dispersers may easily be disrupted since the flowering periods of heathland species are somewhat restricted. Germination requirements, particularly those related to seed size, may also be crucial in determining whether dispersed seeds develop into seedlings and subsequently mature plants. These are likely to be more restrictive for heathland species.

### 10.2.3 Invertebrates

Many insects would expand their natural ranges, especially as the majority occur in the south of Britain where the climate is mildest. Those few species which have a southern boundary of their ranges in northern areas will become endangered. Predicting changes in some invertebrates is very difficult because of the multivariate nature of the factors impinging on them. The key factors affecting both plant (Louda, 1982) and insect populations (Randall, 1982) may vary along spatial (e.g. altitudinal) and temporal gradients (e.g. seasonal) and include climate, predators and parasites and larval food supply. A neat example is the detailed study of the interactive effects of topography, microclimatic heterogeneity and host-plant phenology on the population dynamics of checkerspot butterflies (*Euphydryas editha*) inhabiting serpentine grasslands (Dobkin *et al.*, 1987; Weiss *et al.*, 1988). Microclimatic differences resulting from topographic heterogeneity largely affect the phenology of host-plants and nectar sources of adults. Larval and pupal development and host-plant phenology determine the phase relationship between adult butterfly flight and host-plant senescence, which in turn determine mortality rates of pre-dispersal larvae. Similarly, interesting phenomena may occur on the serpentine soils in the south west of England.

Life-history strategies such as size, shape, diet breadth, voltinism, reproductive potential, ability to fly and overwintering stage may be crucial in determining the response of species to climate change. High surface area to volume ratios will be disadvantageous if the climate changes radically, since both thermal and water balance would be disrupted. Generally, larger insects have less specific temperature requirements and are less prone to desiccation than smaller insects. Rounded insects (e.g. flies, bees) can tolerate a greater range of conditions than elongate insects (e.g. Orthoptera). Round insects would be less adversely affected by global

warming than smaller or elongate insects. Insects which are insulated by surface hairs or have behavioural adaptations such as orientation and posture may be less susceptible to the harmful effects of global warming. Oligophagous and particularly monophagous (i.e. specialist) insect herbivores are more prone to the effects of climate change, since their distribution is limited by the geographical range of one or a few host plant species. Polyphagous species (i.e. generalist) which feed on several host plant species may shift their diet according to prevailing circumstances and may be less prone to extinction. The increase in the length of the growing season may favour those species which have several generations each year (i.e. multivoltine) at the expense of those that can only complete one generation a year (i.e. univoltine). Highly fecund species will also be favoured and will be able to build up large populations. In order to shift latitudinally or altitudinally in response to climate change, winged species would be at an advantage over those which are unable to fly. The larval stages of insects may be particularly vulnerable since they are often soft-bodied and immobile and therefore more prone to desiccation and predation. This is especially the case when larvae develop aboveground, but climate change is unlikely to have major effects on the larval components of the soil fauna.

#### 10.2.4 Generalisations

General principles clearly emerge. Peters and Darling (1985) theorized that a few types of species may be particularly affected by warming trends over the next 100 years.

1. 'Peripheral populations' located near the edge of a species range, that is contracting in response to climate change would be at greater risk than those at the centre or in an expanding edge. This is the case for many lowland heathland species, (e.g. the Sand Lizard and Dartford Warbler) because remnant patches of heathland are largely restricted to the southern counties of Britain so that there is no suitable habitat into which the species can spread northwards.
2. 'Geographically isolated species' would be less likely to have any populations in areas of suitable habitat after climate change, than those whose distribution is more widespread. Some of the most interesting species of grasslands (e.g. orchids) and heathlands (e.g. insectivorous plants) occur in areas that are unsuitable for agriculture, e.g. quarries, mires.
3. 'Genetically impoverished species' may lack the ecotypes adapted to particular climatic conditions, needed to successfully respond to climatic change. If areas of heathland and grassland occur in small, isolated populations (e.g. the Wart-biter), then there will be little possibility for

gene flow between them and inbreeding will occur thereby reducing genetic diversity. This, in turn, increases the likelihood that extinction will occur.

4. 'Specialized species' are generally less tolerant of ecological change because, by definition, some aspect of their life requires a narrow range of environmental conditions (e.g. for seedling establishment or larval development) which might not exist during major climate change. Often the survival of a specialist is tied to the survival of one or a few other species (e.g. butterfly species dependent on ants).

5. 'Poor dispersers'. The increasingly disjunct distribution of suitable habitat may make it very difficult for species not adapted for colonization to spread to new areas if the climate changes. Very specialized forms of plant dispersal involving animal dispersers (e.g. insects, birds) may severely limit the ability of species to spread following climate change.

6. 'Annuals'. Complete reproductive failure by an annual in a given year spells local extinction unless propagules either remain dormant until a more favourable year or arrive from outside sources. Insect species depending on annual hosts run a greater risk of local extinction than those depending on perennials.

### 10.3 Management recommendations

#### 10.3.1 Introduction

Herbaceous vegetation in Britain is very important for the conservation of wildlife and landscape. Its occurrence ranges from species-rich limestone grasslands over calcareous rendzina soils to species-poor lowland heathlands over acidic podsols. Interactions of soil, climate and management are important determinants of plant species composition in both these habitats. Many of the constituent species are from continental ecosystems, most, like the early spider orchid (*Ophrys sphegodes*) in chalk grasslands and the Dartford warbler (*Sylvia undata*) in heathlands, are rarities with a slender foothold in the British Isles. Grasslands and heathlands are plagioclimax communities which are only maintained by external agencies, such as grazing, mowing and burning, which prevent natural succession to scrub and finally woodland.

Based on the relationships of the flora and fauna to the microclimate and vegetation structure (covered in section 10.1) and the predicted effects of climate change (section 10.2), certain suggestions can be made about how to manage both existing habitats and those resulting from restoration projects (e.g. post-industrial sites) (section 10.3.2). This is viewed from

both the stand point of managing particular habitats, such as grassland (section 10.3.3) and heathland (section 10.3.4), and for certain groups or individual species of plants and animals (i.e. rare butterflies (section 10.3.5) and the wart-biter (section 10.3.6). Both existing approaches and alterations to current conservation management are covered.

### 10.3.2 Conservation management

#### a) Introduction

Changes in the distribution of species are greatly influenced by the availability of suitable habitat, any barriers to movement, and the dispersal powers of the species. Habitat fragmentation 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.). Intensively farmed areas or urban developments present insuperable barriers to movement. These barriers are less important to species that disperse long distances so that plant distributions are likely to change more slowly than faunal distributions. Some insects may be good indicators of climate change. However, dispersal rates of some specialist insect herbivores are limited by those of their host plants.

#### b) Nature reserves

##### i) Management

Reserves that suffer from the stresses of altered climate regimes will require carefully planned and increasingly intensive management to prevent species loss. Modifying conditions within reserves to ameliorate the negative effects of climate change may be necessary to preserve some species. Depending on new moisture patterns, irrigation or drainage may be needed, e.g. to maintain wet heath or flood meadow communities. Because of changes in interspecific interactions, competitors and predators may need to be controlled and invading species weeded out, e.g. weed or scrub species. If such measures are unsuccessful, and old reserves do not retain necessary thermal or moisture characteristics, other species may have to be reintroduced to reserves where they become temporarily extinct. An unusually severe drought might cause local extinction in areas where a species would ordinarily survive with minimal management. The re-establishment of species, together with artificial pollination (e.g. of orchids), creation of small gaps in the turf or other specific conditions for establishment (e.g. from the seed bank), corresponding to the regeneration niche, and the harvesting of seed of the less common plants on a reserve