10.3.7 Synthesis

Management is perhaps the most important factor necessary for the conservation of the British flora and fauna. Many grassland and heathland sites have until recent decades had a long history of intensive management by grazing, cutting or burning to which many of the species are uniquely adapted. In cases where appropriate management is reinstated, many of the rarer plant and invertebrate species increase in abundance. This may be more important than factors such as age and size of the site (Gibson, 1986) since when appropriate management is implemented many species may recolonise from nearby 'seed sources' or from surviving soil seed banks (Gibson and Brown, 1991b).

Climate change is only the latest of a series of factors affecting the British flora and fauna. Perhaps more important is the increasing habitat loss and fragmentation resulting from agriculture, forestry and urban development. Particularly in the case of heathlands, this creates insuperable barriers to the dispersal of species which may limit their spread following climate change. In these cases, habitat restoration which increases the extent of suitable habitat for rare species and provides 'corridors' or 'stepping-stones' for their dispersal may represent the best way of preventing extinctions due to climate change.

10.4 Future research relevant to climate change

The problem with much of the research reviewed earlier is that, due to lack of time, resources and money it only covers part of the story. Due to the rapidity of both climate change and habitat destruction, and the multivariate nature of ecological relationships, the current need is for more interdisciplinary studies. Future work should aim, for example, to investigate the following themes for limestone grasslands and lowland heathlands.

1) The relationships between vegetation structure, microclimate and seedling establishment.

2) Monitoring plant communities and populations of specific plant species in respect of specific predictions of climate change.

3) Changes in management needed to ameliorate the negative effects of climate change on the flora and fauna and particularly species of nature conservation interest.

Themes 1) and 2) should initially explore the responses of the plant community, before those of the associated animal community can be understood. They involve field sampling and experimentation. The latter, especially the use of manipulative experiments, is vital to an understanding of the mechanisms under pinning vegetation dynamics. The critical use of well replicated factorial experimental designs permits a 'teasing apart' of the complex interactions between specific variables. Such understanding will enable theme 3) to be explored with scientific rigour. The three themes are not, however, mutually exclusive - taken together they should allow greater scientific awareness of the interaction between climate change and site management.

10.4.1 Vegetation structure, microclimate and seedling establishment

The species composition of plant communities is largely dependent on patterns of seedling regeneration, a process largely influenced by microclimatic and other effects of vegetation structure. The detailed examination of these relationships will provide invaluable information for the management of vegetation for conservation.

Various manipulations of sward structure could be conducted in small plots to investigate the separate roles of different layers of the vegetation. These plots could be centred on individuals of species which either have important effects on seedling establishment or are of nature conservation interest.

The treatments could include cutting the vegetation to different height intervals, removing certain components such as the grass, herb, litter or bryophyte layers, since the contribution of these is likely to change under global warming. They should be applied separately and in combination in order to tease apart the effects. For different plant species, seeds of known weight could be sown into the plots to examine the role of seed size. The plant species should be selected to represent a range of life histories (e.g. annuals, biennials, perennials) or plant strategies (e.g. stress-tolerators, competitors, ruderals). Microclimatic conditions (i.e. temperature, humidity) and patterns of seedling emergence, performance and survival should be recorded within both treated and control plots. Ideally, the study should incorporate both autumn and spring peaks of germination and the treatments could be implemented at different times of year. The detailed effects of the bryophyte layer (Keizer et al., 1985) and neighbouring plants (Ryser, 1993) on seedling establishment have been investigated in continental limestone grasslands. The effects of litter have been studied in North American old-fields (Goldberg & Werner, 1983;

Facelli & Pickett, 1991). There is a lack of such detailed studies for lowland heathlands, particularly those in the south of England. These would complement and extend studies on Scottish heathlands of a) germination and seedling establishment in experimentally created gaps or from sown seed (Miles, 1973, 1974; de Hullu & Gimingham, 1984) and b) vegetational change (Barclay-Estrup, 1971), microclimate (Barclay-Estrup & Gimingham, 1969) and invertebrate populations (Barclay-Estrup, 1973; Gimingham, 1985) in relation to the Calluna cycle. Insect species composition and phenology could also be monitored under a range of treatments, such as those described here. This could incorporate autecological studies of the interactions of an insect herbivore with its host-plant. For heathlands in particular, there is a lack of detailed knowledge of the requirements needed for plants and insects to complete their life cycles in terms of microclimate and vegetation structure. Autecological studies similar to those conducted on the wart-biter and butterflies need to be conducted on other rare invertebrates. For example, very little is known about the requirements of several heathland invertebrates, such as the heath grasshopper (Chorthippus vagans), the speckled footman (Coscinia cribaria), the ground beetle (Carabus nitens) or the raft spider (Dolomedes fimbriatus).

10.4.2 Monitoring of climate change effects

Baseline data on how species (e.g. ranges and reproductive success) and communities (e.g. species composition) respond to climate change is essential if we are to make informed decisions regarding their conservation. These studies would need to be both large scale, covering several field sites, and long-term, lasting a minimum of 3-5 years. Grassland sites should be located in both northern and southern Britain and should include areas in which steep slopes of all aspects are situated close to each other. In heathlands, study sites should include as many different types of heath (e.g. differing in soil moisture levels or management) as possible. Sites should have a long-history of management and a secure system of future management. If the management has changed radically within the recent past, it will be difficult to separate climate change effects from successional processes. Permanent plots (e.g. 3x3 m) could be set-up within each of the sites. These could be located in a randomly stratified manner to assess representative samples of the community and/or subjectively centred on particular plant species (e.g. orchids) or sub-communities (e.g. species-rich patches) of nature conservation interest. Heterogeneities in the soil (e.g. soil depth, pH, organic content, nutrient availability) and seed banks should be assessed, since both may markedly influence the above-ground vegetation (e.g. Fowler, 1992) and may indicate the potential for improved management (e.g. reducing soil fertility, encouraging emergence from the seed bank) Within plots, vegetation structure, species composition and seedling emergence should be recorded. Microclimatic variables could also be measured. More detailed recordings of the fate of individual plants and seedlings could be recorded for species of conservation value. The output and viability of their seeds could also be assessed particularly for those species currently restricted to southern Britain to assess their potential to spread northwards. Similarly, observations could also be made of selected populations of some rarer northern species including non-flowering plants (i.e. bryophytes, pteridophytes), since these are often restricted to isolated, north-facing slopes and therefore prone to extinction.

Very little is known about the dispersal mechanisms of plant species. A knowledge of the dispersal distances of different species and the characteristics which allow them to spread will be invaluable in making predictions about the rate of climate change. Some evidence may be provided by transect studies conducted on set-aside (i.e ex-arable) land adjacent to remnant habitat patches but only for species not present in the arable seed bank. This information may help identify species which may be particularly sensitive to climate change for additional monitoring, research and the development of management techniques. A more manipulative approach to studying climate change effects involves the simulation of predicted climate change, for example, by increasing temperatures using heating cables and adding or excluding water to mimic increased or decreased rainfall. This approach is currently being considered in the TIGER (Terrestrial Initiative in Global Environmental Research) project, e.g. on grassland sites including Upper Seeds in Wytham Woods, Oxfordshire. This type of work should also be conducted on other habitats, such as heathlands, since these may be even more likely to be adversely affected by climate change.

Laboratory studies need to be conducted to support data collected in the field. In particular, the responses of germination, growth, flowering and seed set to changes in temperature and moisture levels need to be investigated under controlled conditions. These studies could involve germination tests and pot-growing plants under controlled conditions (e.g. constant temperature, different watering regimes). Relevant treatments would be chilling (or warming) and drying (or waterlogging) seeds (i.e. to break dormancy) or plants to differing extents and should be applied both singly and in combination. These studies would complement any climatic manipulations conducted in the field. If a range of species, differing in ecological strategies (e.g. seed size), was covered this would also tie-in with any seed sowing experiments and individual plant monitoring conducted in the field.

Similarly, insect eggs or larvae could be placed into a series of experimentally-created vegetation structure types to discover the particular microhabitat in which they flourish best (which may indeed be different from that in which they are normally found). This approach may be particularly suitable in the case of rare invertebrates, such as butterflies and the wart-biter, which have specialised requirements that vary in different stages of the life cycle. Other laboratory work could include measurements of the genetic diversity of populations using electrophoretic techniques, the measurement of DNA content and other ecologically relevant biochemical parameters, such as fructan content. These are often linked to features such as the growth phenology of plant species. For example, high DNA content is associated with a large cell size and in many species, coincides with the ability to store the water soluble carbohydrate, fructan. Such species tend to grow in late winter or early spring by turgor-dependent cell inflation of preformed cells, rather than by the concurrent cell division and expansion (Grime & Hendry, 1990). A lot of this type of work has been conducted in the Sheffield region of northern England and needs to be repeated in southern Britain since considerable interspecific differences may occur as a result of genetic (e.g. gene flow, inbreeding) and environmental (e.g. soil, climate) influences. A recent innovation is the development of 'the temperature gradient tunnel' (Grime & Callaghan, 1988) which greatly simplifies experimental methodology. This type of data can be used to develop models to predict vegetation responses to climate change and the more detailed changes in the phenology and species composition of plant communities (e.g. at latitudinal extremes of ranges). In this context, 'Lusitanian' species (sensu Marrs, 1990), such as the Dorset and Cornish heaths (E. ciliaris and E. vagans), which reach their northern limits in the south-east of England but may expand their British range if the weather becomes warmer and wetter could be chosen for study. To support this approach, 'epidemic' and 'biogeographic' models need to be developed to incorporate the effects of changes in land-use and the precarious nature of populations of rare plant and animals.

Species that are threatened with extinction as a result of climate change should be identified and considered for detailed autecological study. These include arctic-alpine species which are restricted to northern and montane regions where the climate is harsh (e.g. mountain sorrel (Oxyria digyna), yellow mountain saxifrage (Saxifraga aizoides)) of Britain and those which are limited in range by other factors such as the requirement for a specific soil type (e.g. extreme calcicoles or calcifuges). A good approach, pioneered by John Harper, is the detailed study of a closely related group of plants, e.g. a genus. An example, includes the saxifrages (Saxifraga spp.) which includes Lusitanian (i.e south-west), and widely distributed/lowland and arctic-alpine/montane species. The mapping of changes in the distribution of species in the British Isles is an invaluable exercise. Such studies on indicator species or groups may be invaluable in predicting the more general effects of climate change on whole communities and vegetation types. Certain species with strong colonising ability widely regarded as weeds, may spread very rapidly in the event of climate change. Some species may invade Britain by long-distance dispersal from mainland Europe. These species will generally be those with rapid growth, high fecundity and long-distance seed dispersal that may readily colonise productive, disturbed habitats. A checklist of these invasive species, which may also serve as useful indicators, would be invaluable since these species may present problems to conservation (in the way that Brachypodium pinnatum does). Introduced alien species from warmer climates, such as the holm oak (Quercus ilex) and the hottentot fig (Caprobotus edulis), which are already established in the south-west of Britain could be studied.

10.4.3 Revised management in the light of climate change

Long-term plans for endangered or potentially endangered species, and for protected areas should have provisions for climate change (i.e. contingency plans). If climate change does markedly alter existing plant communities, current management will need to be modified to ameliorate negative effects on species of nature conservation interest. Many habitats will experience both a seasonal shift and an extension of the growing season which will mean that overall levels of production will be higher. Under these circumstances the warm, sunny microclimate, upon which the early developmental stages of many rare plant and insect species depend, might be reduced. Site management would need to be intensified to prevent local extinctions and research should be conducted to investigate the most appropriate methods and, perhaps, more especially, the timing of such management. Alternatively, species currently restricted to the southern Britain by their thermophilous nature may spread northwards onto potentially suitable sites which would need to be managed appropriately. Furthermore, on existing sites, populations currently limited by a requirement for a specific type of vegetation structure may increase as suitable microclimatic conditions may occur under a wider range of types vegetation structure.

Site restoration (including transplantation) represents a way of creating suitable sites which may be readily colonised from adjacent habitat remnants. Global warming is a strong argument for enlarging or creating additional protected areas. Multiple refuges provide additional chances that some protected habitat will remain suitable for particular species as climate changes. Moreover, if rare species (e.g. butterflies) which are currently restricted to southern regions of Britain spread northwards, sites to the north of existing populations should be appropriately managed to encourage colonisation. Species could also be artificially introduced to more northerly sites, currently climatically unfavourable, to hasten the rate of spread of rare species. Some sites may be suitable for a rare invertebrate from the point of view of climate, soils and management, but lack (adequate) populations of the host-plant to support a viable colony. In such cases, the sowing and planting of host plants may allow the species to colonise and thrive. The collection of seed from sites where geographically restricted species are presently abundant is a very worthwhile exercise, since seeds may be stored in a suitable manner (i.e. to retain dormancy) for subsequent use. Moreover, many sites may contain large populations of the host-plant but, even if appropriately managed, do not harbour the insect herbivore. In such cases, natural insect colonisation may only occur slowly, if at all, and artificial introduction represents the best strategy.

Although grazing is widely regarded as the the ideal and traditional management, in many cases cutting represents the most practical way to manage herbaceous vegetation types for conservation, particularly where they occur in small, isolated patches. It has a number of practical and economic advantages over grazing which were outlined earlier. Research should focus on the effects of cutting regimes, differing in timing and intensity, on the flora and fauna and could be conducted in conjunction with background monitoring of climate change effects using a parallel series of permanent plots. Initially, cutting regimes could be applied at two intensities (i.e. 'light' and 'heavy') and two different seasons (i.e. 'autumn' and 'spring'). This would give four possible treatments, as well as control plots, a design which could be applied across a wide range of soil types and topography. The frequency at which treatments are implemented could be varied and would clearly need to differ between grassland and heathland sites. 'Turbary' or turf cutting could be implemented as an additional treatment, since this may create large gaps and enable certain species to establish. It is a recognised management on both grasslands and heathlands. It may also get down to a soil layer where dormant seeds are buried (i.e. aggregated) and survive in the absence of predation and pathogenic attack (i.e. the seed bank). This may be an important management tool to increase species which are declining in the sward as a result of inappropriate management or climatic change, but have formed seed banks. Bared areas may serve as foci for the rejuvenation of their populations.

Within these modified management regimes, vegetation structure, species composition and seedling emergence should be assessed to determine effects on plant populations and communities. Microclimatic variables could also be measured. The detailed performance and survival of marked plants and seedlings would give even more precise information and could be focused on plant species of conservation interest.. Invertebrate communities could also be sampled. Taxa which are known to be influenced by vegetation structure (e.g. spiders) and microclimate (e.g. cryptozoic animals) are likely to show the clearest responses, while groups which track the species composition of the plant community are likely to respond more slowly. We are fortunate in that a comprehensive series of studies have already been undertaken into the effects of management in chalk grasslands, largely by cutting, on several insect groups including Heteroptera, Auchenorrhyncha and Coleoptera (Morris, 1967, 1969, 1971a, b, 1973, 1975, 1981a, b; Morris & Lakhani, 1979; Morris & Plant, 1983; Morris & Rispin, 1987, 1988). Future research should be conducted on other types of limestone grassland as well as heathlands. Examination of other invertebrate groups is needed and would complement recent studies into the effects of various sheep grazing regimes upon plant communities (Gibson et al., 1987 a, b; Watt & Gibson, 1988; Gibson & Brown, 1992a, b) and various invertebrate groups (e.g. Auchenorrhyncha (Brown et al, 1992), spiders (Gibson et al., 1992), Coleoptera and Heteroptera (Brown et al., 1990; Gibson et al., 1992b) and leaf miners (Sterling et al., 1992) in a grassland on coralline limestone.