and subsequent re-introduction, are examples of useful conservation techniques.

ii) Location

Information about the changing climate and subsequent ecological responses can be applied to the design of nature reserves, locating them to minimize the effects of changing temperature and moisture regimes. Where northwards shifts in climatic zones are likely, it makes sense to locate reserves as near the northern limit of a species' range as possible, rather than farther south where conditions are likely to become unsuitable. Locating reserves where topography and soil types are heterogeneous could increase the chances that a species' precise temperature and moisture requirements may be met. For example, a large heathland contains a greater variety of habitats including dry heath, wet heath, bog, gorse scrub and acidic grassland. In large reserves, species would have greater chances of finding suitable microclimates or shifting altitudinally or latitudinally. Maximizing the size and number of reserves would enhance the long-term survival of both communities and species, especially if local (sub-) populations are liable to local extinction. If the climate changes radically, small isolated populations with limited genetic variation will be liable to extinction. However, species with large populations and considerable gene flow between populations may have a greater ability to respond to (i.e. buffer) changes.

c) Creating habitats

Habitat restoration involves either the upgrading of existing degraded vegetation or establishing a community on a site without previous plant cover. This approach may be essential if existing habitats become increasingly fragmented. If any of the 'traditional' practices such as grazing, turf-cutting and burning were re-implemented on abandoned grasslands and heathlands, many areas could be restored. Mineral workings which cannot be readily converted to agriculture, forestry, industry or other economic uses provide an excellent opportunity for the practice of ecological restoration. Limestone quarries may support rare orchids and often have the topographic (e.g. slopes, soil heterogeneities), and thereby vegetational and microclimatic variety required to support a diverse flora and fauna. They provide a refuge for certain rare (e.g. early successional) species that might otherwise become extinct. Restoration ecology has greatly expanded in recent years as a result of changes in land-use, such as the set-aside policy. Conservationists have considered the possibility of re-establishing species-rich grasslands on sites which have ceased to be used for crop production (i.e. set-aside fields). However, they have found that the majority of abandoned arable sites do not have a suitable source of seeds nearby and thus restoration is only possible through re-seeding. Even when an adjacent source of seeds is available, the dispersal range of these seeds is short and establishment very limited within a very short time-scale. Natural seed sources (e.g. remnant habitat patches or the soil seed bank) are particularly scarce in the predominantly arable counties. In such cases, the ideal way to restore vegetation is through habitat transplantation in terms of turf fragments or seed-rich topsoil. The creation of new habitats using a variety of techniques may be essential if the climate changes radically since existing sites will no longer be suitable for those species with narrow ecological tolerances.

10.3.3 Grassland management

a) Introduction

Following neolithic forest clearance and many centuries of pastoral management (i.e. grazing, cutting) very little semi-natural grassland remains due to agricultural intensification and remaining areas are small and isolated (i.e. fragmented). This is especially true of calcareous grasslands which occur on limestone soils of high pH and calcium carbonate content. These support ca. 750 plant species including ca. 200 bryophytes and lichens and a very species-rich invertebrate fauna. Species composition varies with soil texture, topography and regional and local climatic variations but management is often the most important factor. Surviving grasslands tend to occur on rocky outcrops or slopes which are to steep to plough and are often unmanaged and are threatened by run-off from arable and atmospheric pollution.

b) Management methods

These differ in their effects on the vegetation, but may achieve similar results. For example, the effects of grazing animals on grassland include fertilisation and trampling, as well as defoliation, whilst only the latter is also characteristic of mowing. Grazers create greater spatial heterogeneity in vegetation structure as a result of their activities. Moreover, different intensities, timing, types of grazing animal and management systems produce different vegetational communities. If the climate changes rapidly, predicting the correct grazing management for sites may be difficult because the phenology of grass growth is likely to be dramatically modified. Mowing may be more appropriate in small, isolated patches of grasslands and where plant and insect phenologies are adapted to a traditional hay cut of given timing and intensity. This type of management may also need to be modified in the light of climate change. Burning is also practised in some 'coarse' grasslands, but may destroy some delicate plant and insect species particularly if droughted vegetation causes fires to burn uncontrolably.

Practical considerations often make it essential for management methods to be simple, especially when they are derived from or closely related to agricultural practices (e.g. grazing). These preserve the character of a site and its 'core communities'. For example, continuous grazing ensures that the input of nutrients is kept low, with consequent maintainance of high floristic diversity. 'Fine tuning' of these management methods conserves the essential features of a site which distinguish it from sites with other uses, such as agriculture. As Morris (1991) states "in contrast to the needs of a few species and breeds which constitute the biodiversity of agricultural stock, the requirements of the components which a conservation manager wishes to maintain are very varied, often specific, and seldom achievable at one point in space and time".

c) Management principles

Ideally, the management of grassland towards any objective should be based on the results of sound research, in order to take into account the varied needs of different species (Grime, 1980). Until recently, management proposals and predictions have to be based on some of the general characteristics of plants that have been shown to be important (Wells, 1980), namely life form, perennial habit and longevity and phenology.

1. Life forms. More than two-thirds of all grassland plants from temperate regions are hemicryptophytes (sensu Raunkiaer, 1934) with their overwintering bud and growing point at or near the surface of the ground. This may be particularly important in terms of the effects of soil temperature on plant growth since the height of the growing point may be important in determining the boundary layer in which they occur. Raunkiaer (1934) showed a clear relationship between life-form and climate.
2. Perennial habit and longevity. 90% of the plant species in temperate grasslands are perennials, many of long life span (Grubb, 1990). Vegetative means of reproduction are widely used by grassland plants and the loss of flowers and seed production by grazing or cutting does not seem important. Flower and seed production by perennials varies considerably, quantity and frequency being a characteristic of each species. The ability of

species to increase seed production if the climate warms up may be a major determinant of future success of their populations particularly if periodic droughts create an unlimited supply of gaps for seedling regeneration. Management should be timed to maximise both seed production and microsite availability and this is particularly crucial for rare species with very precise requirements.

3. Phenology. Biomass and leaf production, flowering, fruit formation, and seed dispersal occur in regular cycles (e.g. seasonal). Knowledge of the phenologies of individual species can help predict the effect of grazing or cutting management on plant growth and reproduction and on insect species whose life-cycles depend on their aerial structures. The pattern of growth of many pasture grasses has been shown to be bimodal with a major peak of production in spring, with a reduced growth rate during and after flowering with a secondary lower peak in late summer. If the climate changes radically, phenological charts may need to be altered. Grass growth may occur earlier in the spring and later in the autumn than at present. This is the time when most seedling establishment takes place. In order to maintain species which regenerate mainly from seed in the sward, it may be necessary to implement management at these times of year. This is a great advantage of winter grazing, since it creates germination microsites for seedling germination without affecting deleteriously plant growth, flowering and seed set which are required for many insects to complete their life-cycles. On the other hand, summer grazing may be particularly deleterious since it may destroy flowers, seeds and other vegetation structures required by insects and remove cool, humid refuges where certain seedlings and insect larvae can survive periodic droughts.

d) Management for individual plant species

More detailed autecological information, as presented in the appendices, may give more precise guidelines for grassland management. For example, the fact that most grassland species have southern distributions and have wide ranges of pH tolerance means that they may readily expand their ranges if the climate warms. Changes in land-use coupled with differences in colonising ability will be a major determinant of future changes in species distributions. Generally, grassland species are evergreen with relatively early flowering phenologies. Examples include Medicago lupulina, Veronica chamaedrys and Viola hirta. This means that they may grow through the winter given suitable conditions. Summer drought is not a major factor since many of the species flower well before the driest part of the year. Radical changes to current management methods may not be necessary to retain these species. Management may need to be relaxed later in the season to prevent damaging effects of summer drought, especially on later flowering species (and invertebrates). Elevated temperatures and growing season shifts would increase grass growth and management may need to be intensified to retain the necessary gaps for seedling regeneration and vegetation structures (e.g. hot spots) required by insects to complete their life-cycles. Small-seeded plant species (e.g. Clinopodium vulgare, Sanguisorba minor) that require warm-dry microsites may require very short vegetation in order to establish, whereas large-seeded species which require chilling (e.g. Viola hirta) may establish best in slightly taller vegetation.

Generally, limestone grassland species are well adapted to warm climates and periodic drought. Many of the rare species of conservation importance are currently restricted to the south-east of England and to south-facing slopes (e.g. orchids). If the climate changes in the direction predicted many of these species have the potential to spread northwards and any shifts in distribution will be positive in terms of conservation. The main factor limiting their spread will be their limited dispersal distances. In this context, site restoration and set-aside schemes present an opportunity to create suitable 'corridors' or 'stepping-stones' to facilitate species expansions. Where territorial shifts of rare species are likely, sites should be located and managed to maximise the chances of successful colonisation and establishment. Fortunately, in terms of soil fertility, sites suitable for conservation are generally less suitable for farming (i.e. low soil fertility). In most cases, levels of grass production will increase under climate change and existing management will need to be intensified on at least part of a site to create the short-turf required by most of the rarities. This is especially true for the formerly species-rich grasslands (i.e pre-myxomatosis) which currently lack appropriate management due to their small size, steep topography, and isolation. Lack of finance and resources are often limiting resources. Thus, the need for voluntary conservation work, donations and other ways of generating income may become more crucial.

e) Management for invertebrates

The condition and structure of the sward is of major importance for many invertebrates. Climate and microclimate are of great significance for invertebrates whose body temperature and hence activity and developmental rates are the result of insolation and ambient air temperature in their immediate vicinity. Climate change is likely to have considerable effects on the invertebrate fauna mediated through changes in grassland vegetation. Changes in management will be required to prevent any negative effects on species of conservation interest. For some species and communities, including most grassland rarities, heavy grazing is essential. An examination of the turf height and broad habitat preferences of those butterflies, Heteroptera and Syrphidae which are confined to calcareous grassland, reveals that the majority are associated with a short turf. Many of these species have declined markedly as a result of myxomatosis and changed farming methods. Sparse vegetation, particularly, on south-facing slopes, is important for species requiring high temperatures (from insolation). However, tall, cool grasslands on level or north-facing slopes also support important components of the grassland fauna and these will decline if the climate warms. In order to conserve this component, management may need to be reduced to create taller, cooler vegetation. Moreover, many insects have different requirements for the various life stages (e.g. egg, larva, pupa, and adult).

Uniform, intensive grazing does not permit the full expression of these animal communities. Other management methods, such as cutting and burning, have slightly different effects. The simplest modification of (continuous) management to cater for communities of short and tall grasslands is rotational management whose timing and frequency of management remain important. For some elements of the fauna, seasonal grazing, every year, has deleterious effects compared with less frequent management. Autumn and winter grazing are generally preferred to management in spring or summer to allow plants to flower and seed and insects to develop.

10.3.4 Heathland management

a) Introduction

Heathland is composed of many branched, evergreen, sclerophyllous ericaceous dwarf shrubs which require cool temperatures and fairly high humidity and grow on free-draining, nutrient-poor and acidic soils. As for grasslands (Rackham, 1986), historical evidence (e.g. pollen records, Godwin, 1944a, b) shows that, particularly in the lowlands, they are clearly the product of human activities and need to be managed (i.e. grazing, burning) to prevent succession to woodland. Traditional practices utilized heathland, e.g. grazing, burning, fuel gathering, and this checked woodland regeneration and kept soil fertility low, thereby helping to perpetuate it. In recent times, there has been a dramatic decline in the overall extent of heathlands and considerable fragmentation has occurred mainly as a result of farming, forestry and urban development (Moore, 1962; Webb & Haskins, 1980). Contrary to grasslands, losses of heathland through lack of grazing, or similar neglect, are small. The continuing fragmentation and isolation is much more important.

b) Management methods and principles

Remaining heathland communities may be damaged by changes in their physical surroundings, such as alterations in the pattern of ground water movements, eutrophication of acid bog systems, and drift of sprays and fertilisers, all of which affect the growth and composition of heathland vegetation. As in calcareous grasslands, successional changes, notably colonisation by scrub and bracken, are a major threat to existing heathlands. The success of scrub encroachment by birch (Betula spp.) and Scots pine (Pinus sylvestris) can be attributed to four main factors. 1) The presence of an abundant, viable seed source. 2) Seed dispersal may be 40-50 m for birch and 100 m for Scots pine. Most heathland patches are relatively small, and once parent trees are established, further rapid invasion occurs. 3) The number of 'safe-sites' for seedling regeneration. 4) Low grazing pressure (Marrs et al., 1986). In most cases, optimum levels of grazing (or cutting) should maintain heathland by preventing tree and scrub invasion without inducing deleterious change, such as conversion into grass-heath. Where scrub invasion has proceeded beyond this stage, trees and bushes may have to be cut, felled, winched and/or chemically treated to prevent further succession towards woodland. The effects of climate change on the rate of scrub invasion may be a particularly important factor determining the future of heathlands and their management. Since birch and pine buds commonly have a chilling requirement, the lack of frosts may be an important factor limiting the growth of these woody species.

One can take two views of heathland management. The whole community can be managed in an attempt to maintain a balance between the various species populations, or the community can be managed as the habitat of selected species. Many of the rare heathland vertebrates which have a high priority for conservation, are species living at edges of their ranges in circumstances where random effects, particularly weather, are greatest. The best example is the Dartford warbler (Sylvia undata), but isolated populations of the sand lizard (Lacerta agilis), natterjack toad (Bufo calamita) and smooth snake (Coronella austrica) are at risk too. Rare invertebrates include the large marsh grasshopper (Stenophyma grossum), the heath grasshopper (Chorthippus vagans), the ladybird spider (Eresus niger), the raft spider (Dolomedes fimbriatus) and the scarce ischnura dragonfly (Ischnura pumilio) (Webb, 1986).

c) Management for individual plant species

The aim of heathland management is to prevent invasion of scrub, trees, and bracken and to produce, by rotational management, a mosaic of ericaceous vegetation of different ages, representing the entire growth cycle of Calluna. Heathland plant species vary in their ecological attributes and this may critically determine changes in their distribution resulting from climate change and the management needed to alleviate these effects. For example, species with wide pH tolerances (e.g. Hypericum pulchrum, Juncus acutiflorus, Molinia caerulea) may colonise a greater variety of sites (i.e. soil types) than species with a very narrow requirement for acidic soils (e.g. Ulex europaeus, Vaccinum myrtillus). This should be taken into account when selecting and managing sites for the protection of these species. Differences in the phenology of growth and flowering may also determine the response of species to climate change. Later flowering species (e.g. Calluna vulgaris, Teucrium scorodonia) may be more prone to the deleterious effects of summer drought than earlier flowering species (Polygala serpyllifolia, Rumex acetosella). Management may need to be earlier in the year to prevent this.

d) Management for invertebrates

The continuity of the plant cover should be maintained, with an adequate representation of the different compositional and structural types of vegetation, though bare sandy areas are also important. The latter are the habitat of tiger beetles (Cicindelinae) and sand wasps (Ammophila spp.), as well as being valuable to reptiles as basking sites. Successional changes resulting from lack of management may reduce the availability of this component and it may have to be artificially created in order to conserve these species. The richest invertebrate fauna is generally associated with the mature and degenerate stands of heather. However, there should also be adequate representation of various types of heathland scrub and the associated aquatic habitats. A commonly overlooked feature of invertebrate conservation is the fact that many insects require different habitats for their larval and adult stages, and often a further one for the pupal stage. These need to be provided adjacent to one another for completion of the life cycle. Uniform burning of large areas of heathland may therefore be unsuitable. Sand wasps require bare sand patches to construct their larval burrows, but also need mature heathland vegetation to hunt for the caterpillars with which they provision their burrows (Webb, 1986). A definite fine-scale mosaic needs to be created in the vegetation in order to fulfill both the precise requirements of individual rare species and maintain a generally high invertebrate diversity. Here, grazing may be the ideal management. The precise timing and intensity of management needed to create this mosaic will clearly need to be changed to accommodate the effects of climate change. In addition, the surrounding habitats may modify the composition of the fauna, and this is particularly important on small, isolated heathlands (Webb et al., 1984; Webb, 1989).

Traditionally, it was thought that invertebrate communities will be maintained if the plant communities are managed satisfactorily, but it is now realised that the requirements of many species are precise. This has been ably demonstrated for butterflies, where even a few millimetres difference in turf height renders an area unsuitable for some species, even though its food plant may be growing in abundance (Thomas, 1984). The silver-studded blue (Plebejus argus) is very much a lowland heathland species. These butterflies require a certain vegetation height and the correct proportion of open space and bare ground in their habitat (Thomas C. D., 1985 a, b). Their heathland distribution may, in part, be determined by the distribution of ants which also have specific habitat preferences (Brian, 1964; Brian et al., 1976). This species may be very vulnerable to changes in vegetation structure and microclimate and a specific management programme may be required inorder to conserve it.

e) Management for vertebrates

i) Reptiles

Areas for the conservation of single species should be set-aside and not form part of the burning rotation. These should include areas of unburnt or older heather which may be important for the conservation of reptiles, e.g the sand lizard, since fire may be harmful to them (Corbett & Tamarind, 1979). In Britain, the optimum habitat of the sand lizard is mature, dry heathland with a well developed litter layer and bare, hot, sandy areas which are not shaded. The choice of habitat does not depend on the richness of plant species present, but upon the structural diversity of the vegetation. The most favourable sites harbour great structural diversity with many borders with other vegetation types (which increases the abundance of invertebrate prey) and open soil or sand for basking enabling both efficient thermoregulation and foraging (House & Spellerberg, 1983). Basking sites are a particularly important feature of the lizard habitat particularly during spring (Jackson, 1978). In general, these have a south-facing aspect, small-scale variation in the soil surface in the form of ruts and depressions, and with moss, lichen and dark-covered surfaces. In the early morning and and late afternoon, lizards may frequently be seen basking on south-east and south-west facing slopes respectively.

The preferred habitat of the smooth snake is dry, sandy slopes covered with mature Calluna heath with dwarf gorse, sometimes with a woodland nearby and often adjacent to a wet heath or a stream. The soil must have a texture suitable for the snakes to burrow (Spellerberg & Phelps, 1977). Fecundity is determined by weather and food supply: habitat management should ensure that females have adequate basking conditions for incubation by making use of natural topographic variation or, where this is insufficient, by the creation of embankments. Management by burning is also harmful, since the snakes cannot survive the fire or recolonise quickly (Goddard, 1983). Reptiles may generally benefit if the climate warms up through greater winter survival, faster development rates, higher fecundity and greater food availability. The habitat requirements may shift and detailed studies would determine whether this is the case.

ii) The Dartford warbler (Sylvia undata)

Of all the heathland rarities, the Dartford warbler was considered by Moore (1962) to have the highest priority for conservation. It is a bird of maritime western Europe and reaches the northern limit of its range in southern England. Its populations fluctuate a great deal in relation to climatic variations. Unlike other British warblers, it overwinters in Britain and, as a result suffers considerable mortality if winters are particularly severe. In future, the extreme conditions that have led to large numbers of bird deaths in Britain in the past are less likely to occur in future (Marquiss & Newton, 1990). Populations of species, such as the Dartford warbler, traditionally viewed as vulnerable to cold weather will not suffer major overwinter declines and will become more often limited by habitat rather than weather. It is an ecotone species which occurs where Calluna/Erica is diversified by gorse, invading trees, or by wet valleys, where prey is especially abundant when compared with other open habitats. An analysis of 202 territories in Dorset and 180 in the New Forest (Bibby & Tubbs, 1975) showed that gorse (Ulex europaeus) was a component in 83 and 75% of them, with ericaceous ground vegetation in 79 and 73% of territories. Gorse has a more abundant invertebrate fauna (Bibby, 1979) than Calluna and good stands are important feeding areas. Unfortunately, the fact that gorse is highly calcifuge means it may decline if the climate warms. Management should therefore be geared to allow gorse to regenerate and increase.

f) Revised management of heathlands

i) Burning

Calluna is shallow-rooted as evidenced by the effects of sod-cutting to different depths on heathland regeneration (Werger et al., 1985). It grows best on damp soils and in a cool, moist climate. If the climate changes the extent of heathlands might decrease as a result of drought. Drought might also increase the risk of accidental or uncontrollable fires which may pose a threat to the rare reptiles. This may increase the representation of the 'pioneer' phase which would increase floristic diversity since the dense canopy of Calluna in the mature stages prevents the establishment and growth of other plant species. However, the higher temperatures within fires might destroy the seeds and rootstocks needed for heathland regeneration which would encourage grassland and scrub invasion. Where possible, drainage patterns could be modified to prevent drought from occurring. Burning may need to be practised earlier in the year and/or less frequently to prevent damaging fires and increase the proportion of mature heather respectively. An adequate representation of the 'building' and 'mature' phase may be particularly important for the conservation of vertebrate species.

ii) Cutting

Alternatively, heathlands could be managed by cutting which although more labour intensive, minimizes the deleterious effects of fires and may provide a source of animal feed, fuel, or other raw materials. Many of the constraints imposed by burning management are absent. Cutting is not limited to particular times of year or to heathlands of a certain minimum size and its intensity may be more easily controlled. Fires may destroy some invertebrate species which would otherwise thrive on heathlands. Cutting management thereby offers greater potential for both diversifying heathlands and meeting the requirements of rare species since different patches can be cut at different heights and seasons and at different frequencies. It is likely that cutting would need to implemented more frequently than burning since the regenerative capacity of Calluna may not be reduced to the same extent. Mowing and the removal of the cut heather as bales, as practised in the New Forest, may be more effective than burning to remove nutrients. Turbary, or sod cutting, as practised by Diemont and Heil (1984) on heathland areas in the Netherlands may be even more effective in reducing nutrient levels. The cutting or turf is thought to have been an important factor in the formation and maintainance of British lowland heathlands. Werger et al. (1985) showed that there was no practical advantage of sod-cutting more deeply than the A1 horizon.

10.3.5 Butterfly conservation

Detailed studies of butterfly species have been conducted with the aim of solving conservation problems. These have revealed that the habitats occupied by the immature stages are more specialized and transient than had previously been thought. The high levels of insolation which occur on disturbed sites are particularly important in the early stages of insect development. Because of their precise requirements butterflies may be used as sensitive indicators of changes in vegetation structure and microclimate.

Grazing is the management method which best maintains a mosaic of early seral vegetation needed for larval development and taller vegetation which provides the adult butterfly with flowers for nectar, and suitable structures for shelter and resting places or territorial perches. Clearings may only be suitable for certain species when made in particular parts of a site, e.g. south-facing slopes. Modifying the topography of certain grassland sites may increase the potential diversity of butterfly habitats, and perhaps, if the soil is sufficiently infertile, reduce the management needed. Such landscaping may create the warm and sheltered sparse turf that is needed by so many rarities, without recourse to regular grazing. However, taking butterflies as a whole, again some species breed primarily in short-grazed turf, others in medium turf and others still in long turf. At one extreme are species such as the Adonis blue (Lysandra bellargus)(Thomas, 1983a) and silver-spotted skipper (Hesperia comma) (Thomas et al., 1986) which require very short or broken turf, and at the other are species such as the Lulworth skipper, Thymelicus acteon, (Thomas, 1983b) which prefers very long grass swards. The latter species is actually increasing at present due to the spread of its host-plant Brachypodium pinnatum.

If the climate warms a greater range of sites will provide suitable oviposition requirements. Rare butterfly species could increase their population sizes within existing sites and may spread northwards onto formerly unsuitable sites. The rate of spread may be limited by the distribution of the host plant although certain species may begin to feed on other plant species (i.e. host shifts). For example, in central-southern Europe Maculinea arion may oviposit on Origanum vulgare. If there is no increase in precipitation, temperature increases may either increase or decrease grass growth depending on the moisture status of the soil. On drought-prone sites with very thin soil management may need to be relaxed so that the amount of taller turf and flowers needed for other stages of the life-cycle increases. On other sites where moisture is not limiting the sward may grow very tall and management will need to be intensified in order to create suitable ovipositing sites. If the climate warms the temperature conditions required for larval development may occur in slightly taller swards than is currently the case. For example, the lowlands of central-southern Europe, where the climate is hotter, adequate densities of the ant Myrmica sabuleti to support Maculinea arion occur in locally cool swards 20-60 cm tall.

10.3.6 Conserving the wart-biter

Brown and Cherrill (1992a) studied the ecology of the ground-dwelling bush cricket (Decticus verrucivorous) which is widespread in continental Europe, but declining at the northern end of its range. The distribution of each of the seven nymphal instars and adults was described in relation to vegetation structure within a chalk grassland in southern England. First instars were strongly associated with short sparse turf reflecting the oviposition behaviour of females. Subsequently, early instars were also found in short, open turf, but at the fifth moult a distinct shift in distribution to dense grass tussocks occurred. Late instars and adults were strongly associated with these structures, probably to avoid vertebrate predators. Mean temperatures within tussocks were lower than in short turf, but these highly mobile stages actively thermoregulate by basking on the sides of tussocks. In contrast, areas of short turf may be crucial for the development of the smaller and early instars and eggs (i.e. thermal requirements). Significantly, it is this component of the mosaic which is in danger of being lost as a result of recent changes in the economics of livestock grazing at Wart-biter's sites. Those sites with few Wart-biters are those which are currently undergrazed, with the least short turf and lowest diversity of vegetation height profiles.

Cherrill and Brown (1990a) concluded, like several rare butterfly species, that a fine mosaic of closely-grazed turf, dense tussocks and intermediate structures and intermediate structures must be created and/or maintained at the species northern-most sites, if its present distribution is not to contract. Rotational management is a possibility but the conservation of such species as D. verrucivorous which are (i) restricted to relatively small areas within reserves, (ii) relatively immobile and (iii) sensitive to subtle changes in vegetation structure, requires continuity of suitable conditions within those areas where they are currently found. Fortunately, the wart-biter's need for a range of vegetation structures within a site suggests that management need not conflict with the conservation of communities of co-occurring invertebrate species, which individually have narrower requirements but en masse require a diverse flora. For example, both the adonis blue butterfly (L. bellargus), requiring short turf, and marbled white butterfly (Melanargia galathea), requiring grass tussocks are abundant on the same chalk grassland site where the mosaic of vegetation structures is maintained by cattle grazing (Cherrill & Brown, 1992a).

If the climate changes this may affect populations both directly through effects on insect physiology (e.g. rates of development) and indirectly by altering the vegetational mosaic upon which the wart-biter depends. Cherrill and Brown (1991a) studied the effects of the summer of 1989, which was unusually dry, warm and sunny, on the phenology of the wart-biter. The period May to October was equal fourth warmest since records began in 1659 and there were more sunshine hours than in any year since 1909. In comparison with the previous two years, adult recruitment was completed four of five weeks earlier and there was less variance between individuals in the timing of final ecdysis. Nymphal densities were lower in 1989 than 1988, while the converse was true for adult densities suggesting that nymphal survival may have been enhanced by the warmer weather of 1989. Ingrish (1978) demonstrated that nymphal development rates are temperature-dependent being most rapid at 33 ^{o}C and ceasing below 20 ^{o}C. Between 1967 and 1987 the number of adults in a given year were found to be strongly correlated with the number of sunshine hours in the summer two years before due to the two-year post-embryonic phase (Haes et al., 1990). Hence, the full impact of the weather of 1989 was not evident until 1991 onwards and the success of any conservation measures will only be apparent after periods of several years. The wart-biter is currently restricted to the southern counties by its thermophilous nature. If the climate warms its distribution may expand northwards and so reserves should be established and managed to the north of existing colonies.

If drought increased then this may increase the proportion of short-turf for oviposition (in the spring) but decrease the proportion of taller turf needed to complete later stages of the life-cycle (in the summer). In order to preserve the cool-moist microclimate and shelter from predators management would need to be relaxed. However, if elevated temperatures and/or additional rainfall increased grass growth the short-turf microclimate would be in short supply and management would need to be intensified. This is the more serious threat to existing populations since the availability of oviposition sites is the major factor limiting populations of both the wart-biter and several rare butterfly species.