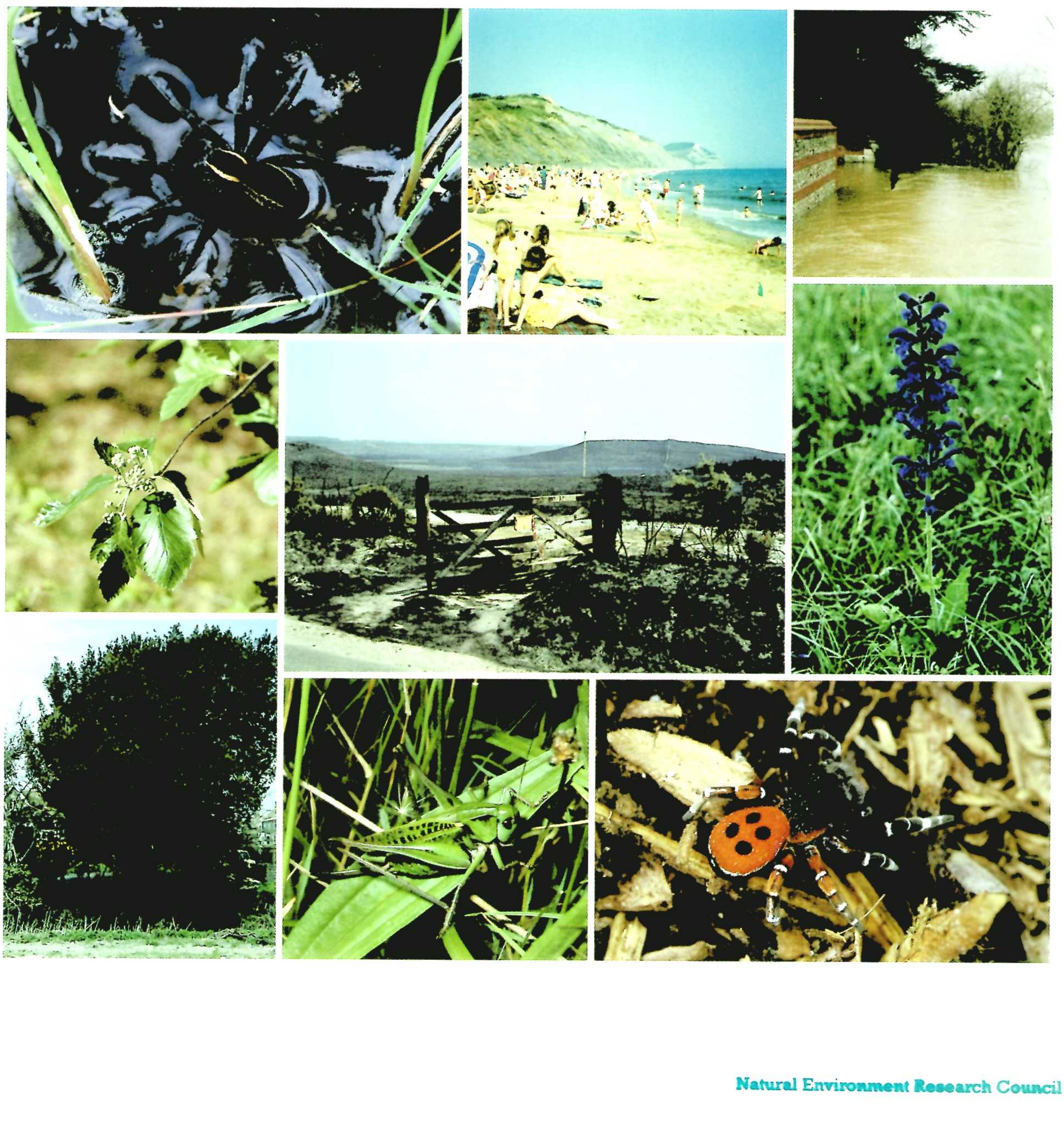
Institute of Terrestrial Ecology

Climate change and rare species in Britain



Natural Environment Research Council

Cover photographs

Top	left	Raft spider *(Dolomedes fimbriatus)* (photo L K Ward)
	centre	Enjoyment of a hot summer (photo J C Wardlaw)
	right	Flood in winter 1992 (photo J C Wardlaw)
Middle	left	Flowers of *Sorbus lancastriensis,* a rare species of white beam (photo L K Ward)
	centre	Hartland Moor National Nature Reserve, after 1976 fire (photo R G Snazell)
	right	Meadow clary *(Salvia pratensis)*, a rare downland flower species (photo L K Ward)
Bottom	left	Salt damage to yew *(Taxus baccata)* growing more than ten miles inland, after an unusual gale in 1990 (photo L K Ward)
	centre	Wart-biter cricket *(Decticus verrucivorus)* (photo L K Ward)
	right	Ladybird spider *(Eresus niger)* (photo J A Grant)

Global warming may have both harmful and beneficial effects for humans and wild plants and animals

Warmer summers might benefit the holiday industry (top centre) and heat-loving species (bottom right), but increased summer droughts might harm wetland species (top left) Warming may lead to a greater frequency of extreme weather events resulting in more fires (centre), floods (top right) and gale damage (bottom left) that may affect other rare species (middle left & right, bottom centre) which might not be harmed directly by increased temperatures

This is a summary report of a study into how climate change might affect Britain's rare and endangered wild species, commissioned by Nuclear Electric plc. It comprised three unpublished reports:

- ***The impacts of climate change on Britain's threatened species,***
  by M G Telfer & B C Eversham, Biological Records Centre, ITE Monks Wood, Abbots Ripton, Huntingdon, Cambs PE17 2LS

- ***Vegetation and climate. a 35-year study in road verges at Bibury, Gloucestershire, and a 21-year study in chalk grassland at Aston Rowant, Oxfordshire,***
  by R Hunt, NERC Unit of Comparative Plant Ecology, The University, Sheffield S10 2TN

- ***An analysis of the occurrence of rare birds in Britain in relation to weather,***
  by A Austin, N A Clark, J J D Greenwood & M M Rehfisch, British Trust for Ornithology, The Nunnery, Thetford, Norfolk IP2 2PU

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Main points from the study

The direct effects on the distributions of Britain's rare and endangered species were estimated by measuring the extent to which their present distributions might be reduced under different climate change scenarios. A range of scenarios, some mutually exclusive, were used because of the considerable uncertainty about the precise nature of the climate changes that might affect Britain.

Twenty-nine per cent of rare plant and animal species might be directly adversely affected by a 2°C rise in mean annual temperature, whereas about 50% could be affected by changes in continentality (difference between summer maximum and winter minimum mean temperatures) Changes in rainfall could have the most impact, with about 70% of rare species being adversely affected if rainfall increased

When patterns of responses were combined, five groups of rare plant and animal species were identified About 23% were geographically widespread and should not be directly affected by any climate change scenario, 17% might be affected if rainfall increased significantly while 33% were associated with continental conditions in Britain and could suffer if winters became warmer and wetter or summers became wetter About 20% had a north-western distribution This group contained many subarctic and alpine species that might suffer if the climate were to become generally warmer and drier The remainder were south-western species that appeared sensitive to changes in rainfall

An analysis of the records of Britain's rare breeding and passage migrant bird species was made to determine any response to fluctuations in annual weather conditions.

Approximately half were likely to suffer from drier summer conditions or cold wet winters However, increased temperatures, providing summer rainfall was maintained, could benefit one third of the rare bird species

An analysis of weather on grassland community structure was made using data from two long-term studies because the habitats of many British rare plant and animal species include such intensively managed ecosystems.

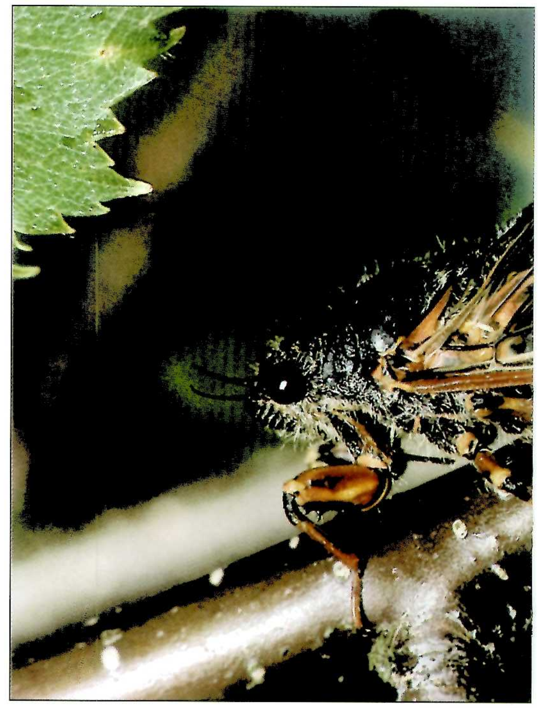
The predicted impacts of climate change on the intensively managed habitats, found mostly in southern England, might be controlled by alternative management strategies The problems associated with this option were illustrated by considering two grassland butterfly species However, intensive management is not a viable option for many natural climax or more mature biotopes, such as ancient woodlands and mountain tops

Global warming is likely to change the climate of our world during the next century – the average temperature of Great Britain may rise by 2°C or more. A 2°C warmer climate was last experienced in northern Europe, during the mid-Holocene optimum, 5 500–6000 years ago and before that during the Pliocene, 4 million years ago. Most of the intervening periods have been colder than at present. Climate change will affect all aspects of our land use, including farming, forestry, industry, urbanisation, recreation and wildlife resources (references 1,4,5).

The possible transformation of our countryside and the effects on common, well-loved, wild species have alarmed people. For example, predictions that most 'bluebell woods' will be lost from a warmer Britain have caused considerable public concern.

Many wild species are restricted to just a few populations which are already under local threat of extinction from human interference with their habitats. The effects of a changing climate may be the final straw for some. The first species' extinctions in Britain, attributable to climate change, are expected from among these species.

This booklet summarises the research, undertaken for Nuclear Electric plc, on the probable effects of climate change on Britain's threatened species that are listed in *Red Data Books* or equivalent lists (see page 9).



The New Forest cicada (*Cicadetta montana*) is an example of a species with a very restricted distribution in Britain.

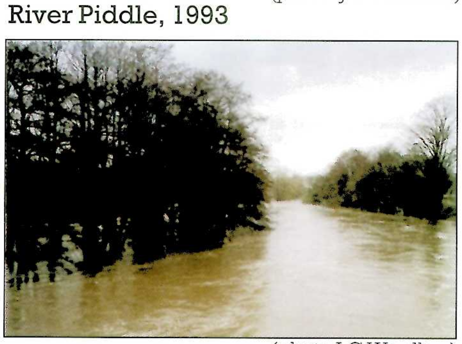
Fire in the New Forest

(photo L K Ward)

River Piddle, 1990

(photo J C Wardlaw)

River Piddle, 1993



(photo J C Wardlaw)

Climate change

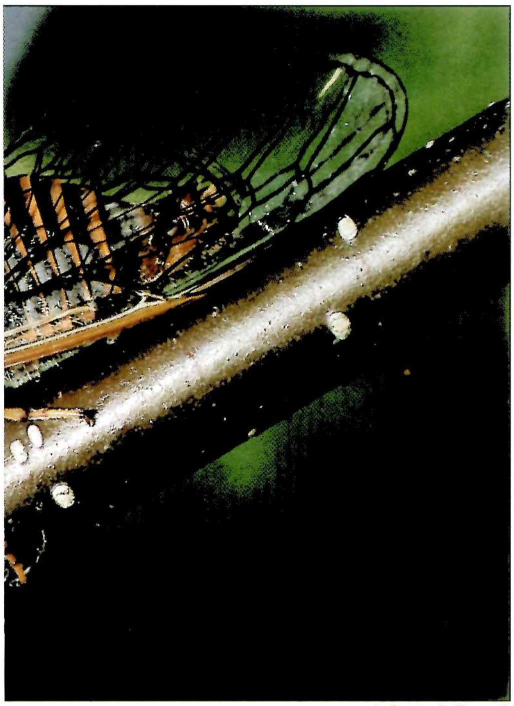
The overall temperature of earth is a balance obtained when the amount of solar energy reaching earth equals the quantity of heat lost back into space. Solar energy has varied over the earth's history but, in the short term, it is fairly constant.

Industrially based societies produce several 'greenhouse gases', so-called because they increase the insulating effect of the atmosphere, trapping more heat and causing the earth's temperature to rise. The most important is carbon dioxide which is liberated mainly by burning fossil fuels.

By the end of the 21st century, the combined effect of adding greenhouse gases to the atmosphere will be equivalent to a doubling of the present amount of atmospheric carbon dioxide (CO_2) (references 4,5).

Models of global atmospheric circulation that simulate patterns of present climate predict a consequential rise in temperatures of 2–6°C above the present average. Worldwide, surface temperatures could increase by between 1.5°C and 4.5°C, averaging about 2.5°C, resulting in an overall increase in rainfall of between 0% and 16%.

Extreme weather events such as droughts, gales and floods (cover and left) will become more frequent according to the forecasts of some models, but their change in frequency cannot be predicted with certainty at the present time.



(photo J Grant)

Although previously recorded from several parts of southern England, it is now found at only one site in the New Forest.

Distribution and threat of extinction

The recorded distribution of a species gives an indication of its geographical range

Range is bounded by the climate to which the species is adapted, combined with other physiographical and biotic factors.

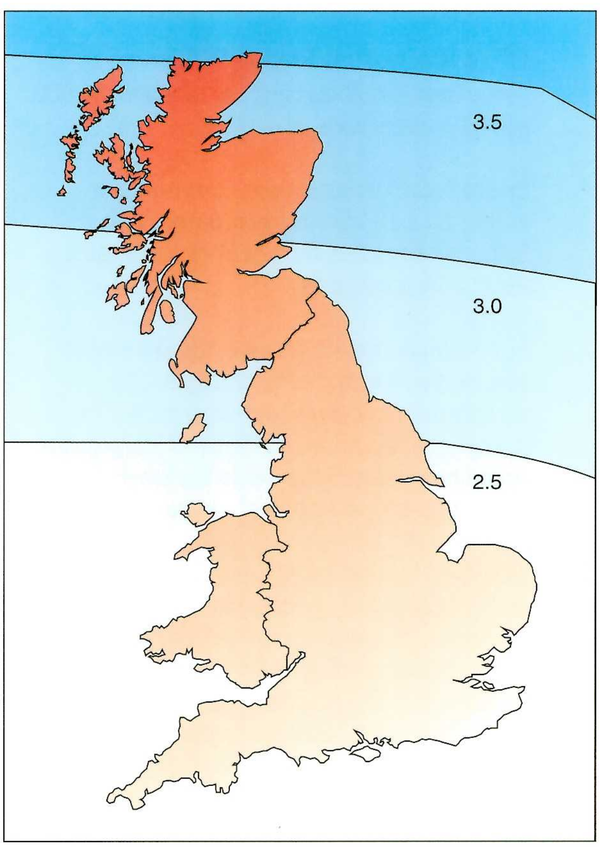
Organisms are not equally abundant

A few species are very common and most are rare. The definition of rarity is subjective; it depends upon the extent of the geographic range of a species, the number of different natural communities or biotopes in which it is found, and the size of local populations. All species can be ordered in these three scales (reference 6).

The rarest species live in few biotopes and always have small populations

These small populations are liable to chance local extinction. Widespread species of this type are in less danger of global extinction than geographically restricted, endemic species because most threats are local. Some are man-made, for example urbanisation; others such as coastal erosion are more natural. Climate change will affect rare species over their entire geographical range so that both widespread and restricted species are threatened with extinction.

Increase in mean winter temperatures by the year 2050



Predictions for 21st century Britain

- **Summers** could be 2°C warmer throughout Britain by the second half of the 21st century (reference 4).
- **Winters** will be relatively milder, particularly in Scotland where winter temperatures might be almost 4°C warmer than at present.
- **Rainfall prediction** is very difficult because British weather is dominated by variable westerly, rain-bearing low-pressure systems, that make even short-term forecasts unreliable.
- **It is estimated** that winter rainfall will increase by about 8%, while summer rainfall will remain more or less the same. The increased summer evapotranspiration will result in drier soils, particularly in East Anglia.

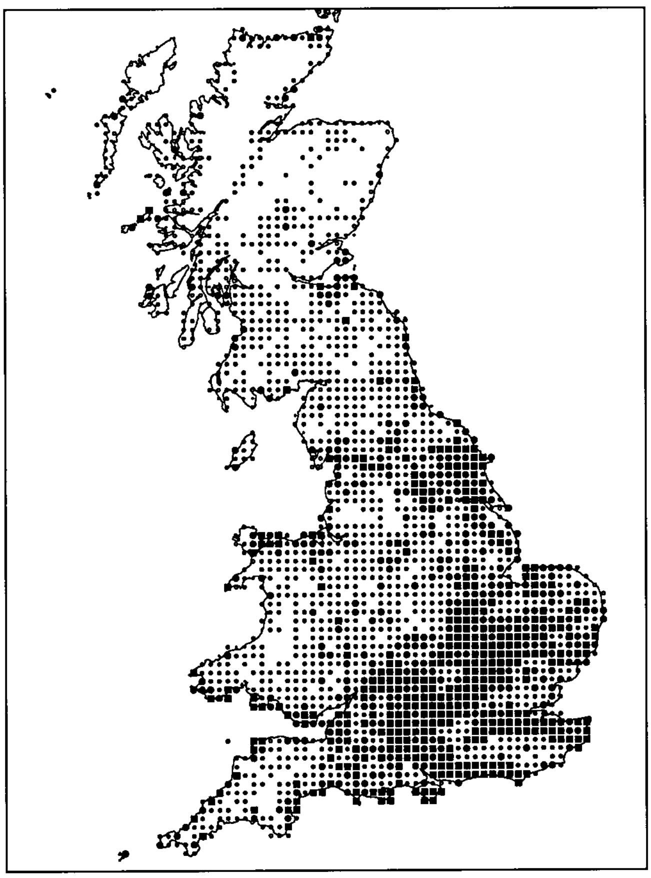
Groups studied

The Biological Records Centre holds records on the distribution of almost all the *Red Data Book* species in 16 groups of plants and animals The study was restricted, therefore, to these groups

On average, 18% of the species in each group are listed in *Red Data Books* There is considerable variation <1% of micro-moths have *Red Data Book* status, whereas all species of British bat are considered to be threatened

The distributions of many invertebrate species are poorly known, compared with plants and vertebrates Butterflies are the best recorded group of invertebrates

Abundance of calcareous grassland molluscs



■ 5+ species
● 4 species
• 3 species
o 2 species
• 1 species

The taxonomic
with the number of species
(1 = Endangered, 2 = Vulnerable,
formerly native but now believed to be extinct)

			RDB status
Taxonomic group	1	2	3
Ferns	3	2	3
Flowering plants	66	91	148
Non-marine molluscs	10	7	12
Millipedes			2
Centipedes			3
Dragonflies	4	2	3
Grasshoppers & crickets	3	2	1
Butterflies	2	3	4
Macro-moths	21	12	53
Micro-moths	4	7	
Woodlice		1	1
Amphibians			1
Reptiles			2
Bats	3	10	2
Rodents		1	
Carnivorous mammals		1	
TOTAL	116	139	235

* Total of flowering plants includes many non-native species

ITE's Biological Records Centre holds more than 6 million records of some 10 000 species (reference 3)

Species occurrences are summarised within 10 x 10 kilometre squares Great Britain is covered by a grid of more than 2800 10 km squares

For well-recorded species, the data base can be used to monitor changes of distribution in both space and time For many rarer species, maps of 10 km squares containing records provide the best indication of that species' range

The data can be combined in many ways to provide maps of species densities For example, the map on the left depicts the co-occurrence of grassland mollusc species that are considered to be associated with calcareous conditions Squares containing high densities more or less indicate the areas of calcareous grassland in Britain

groups studied,
in four *RDB* status categories
3 = Rare, App = appended species,

App	Total *RDB*	% *RDB*	Total no. of species
	8	5.4	148
	305	6.5	4662+
	29	13.8	210
	2	1.8	107
	3	6.0	50
	9	21.9	41
	6	20.0	30
3	14	25.0	56
13	99	11.0	*c*900
	11	0.7	*c*1500
	2	4.0	50
	1	16.7	6
	2	33.7	6
	15	100	15
	1	7.1	14
	1	11.1	9
16	506		*c*7800

***Red Data Book* species**

Red Data Books (*RDBs*) are published locally, nationally and internationally by bodies responsible for species conservation. *RDBs* have not been published for all groups. Some have not yet been considered, others have provisional lists drawn up using *RDB* criteria.

Red Data Books list those species that are believed by experts to be under threat of extinction. Although rarity alone does not guarantee a species' inclusion, in practice the rarest species are usually perceived as being under threat.

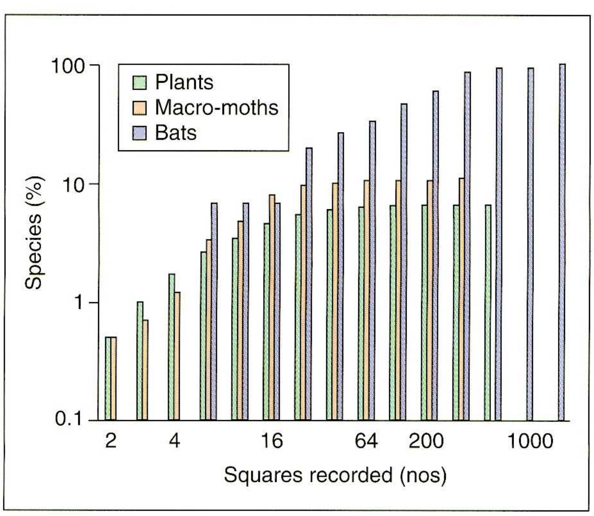
The study summarised here considered only species in British *RDBs* or on British provisional lists. Appended species, that is species that were formerly native but are now believed to be extinct, were not used. The three main categories of threat are:

Endangered (*RDB1*) Species in danger of extinction and which are unlikely to survive without remedial measures. Criteria for inclusion embrace species known only from a single population and species that have shown a rapid, recent decline and now exist in less than five 10 km squares.

Vulnerable (*RDB2*) Species likely to become endangered if the causal factors for decline continue. They include species declining throughout their range, species in vulnerable biotopes, and species with low populations.

Rare (*RDB3*) Species with small populations but at present regarded as not under any specific threat.

Cumulative percentage of species



Taxonomic groups containing many species, such as flowering plants and macro-moths, contain *Red Data Book* species that mostly have restricted distributions. The majority of *RDB* species are recorded from less than 60 10 km squares (left).

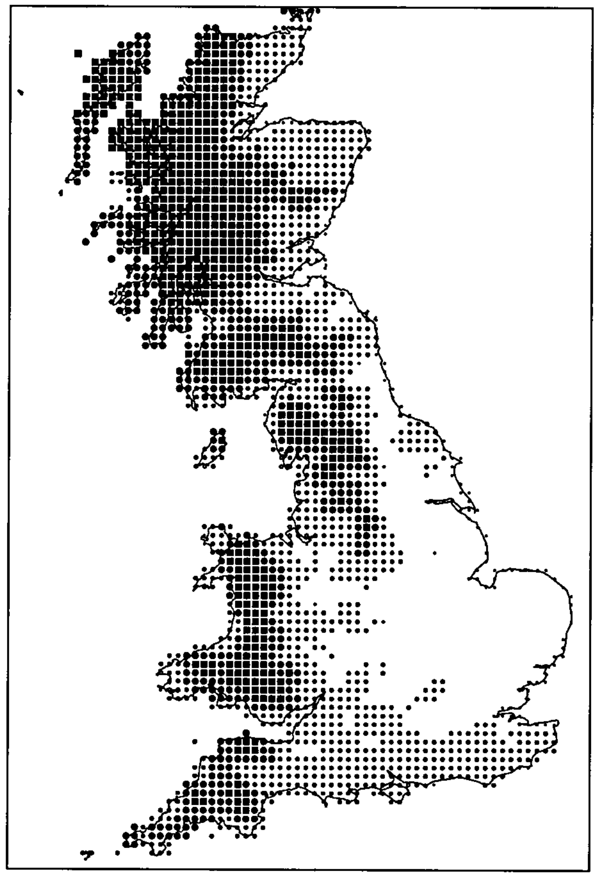
***Red Data Book* species need not have restricted distributions.** There are few British bat species. They are mostly widespread but all are threatened by human interference. Therefore, all species are on *RDB* lists despite some species having been recorded in more than half of the 10 km squares in Britain.

Britain's weather varies greatly from day to day
It is dominated by rain-bearing low-pressure systems, moving in from the west

Rainfall is greatest on the high mountains of Wales and west Scotland, where almost twice as much falls as on the flat lands of East Anglia

Temperatures are warmest in southern England which, on average, is 3–4 °C warmer than Scotland The western seaboard is warmer than expected, especially in winter, because of the influence of the Gulf Stream

Continentality, measured by the difference between winter and summer temperatures, is greatest in the south-east of England



Annual rainfall
10 km squares >1470 mm year^{-1} are indicated by ■
Those <725 mm year^{-1} are indicated by a dot

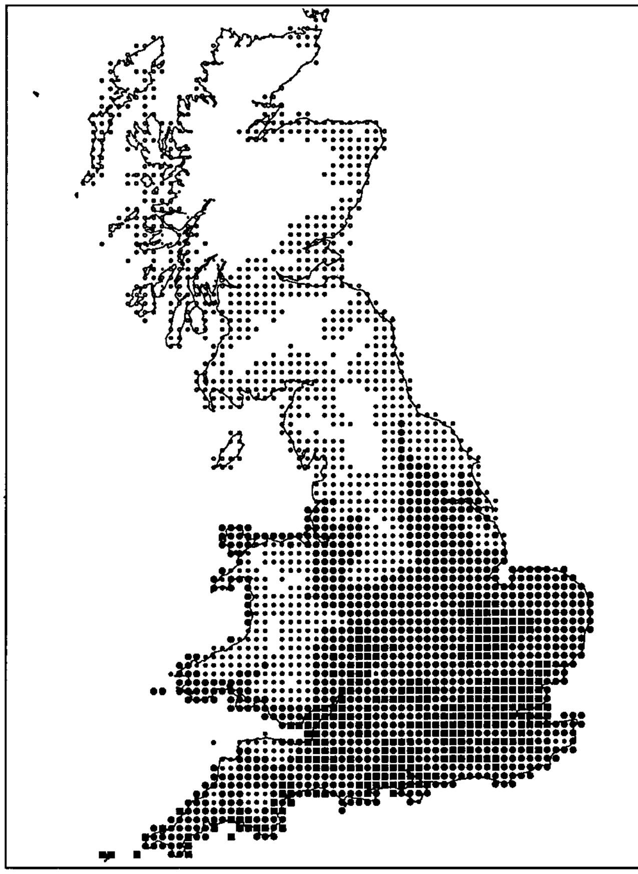
Species distributions and climate were linked by considering meteorological records on the same 10 km square basis as the species' distributions Using the same mapping techniques as those used for generating species' distribution, maps were produced to illustrate the variation in Britain's climate (above) Intervals were chosen to give approximately the same number of 10 km squares in each class

Estimation of range vulnerability – the climate space or 'envelope' for each species was defined by the extremes of the climatic variables, associated with squares containing records for that species (occupied squares) If any occupied square was among the 20% most extreme in Britain (eg 20% wettest), then the species was assumed not to be limited by that variable (ie it could tolerate any reasonable increase in rainfall) This effectively precluded contradictions, such as assuming a species to be limited by temperature in Britain when it is known to occur in hotter places elsewhere in Europe

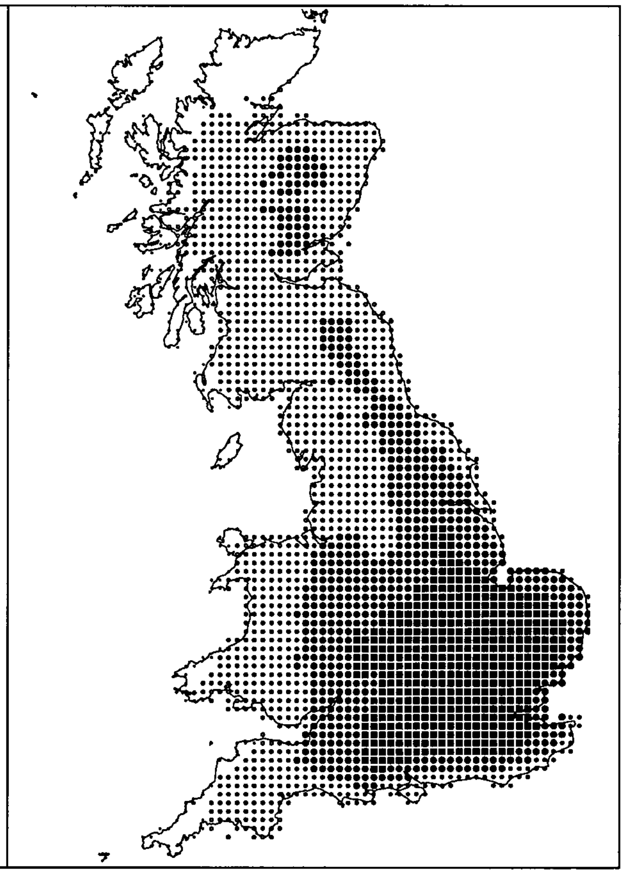
The most probable climate change scenarios for Britain can be simulated approximately by altering annual mean temperature, the mean July maximum minus the mean January minimum temperatures (continentality) and the mean annual rainfall (Table facing) The pattern of responses to change in each of the three climatic parameters was complicated, especially in the cases of continentality and rainfall, where both decreases and increases on the present values have been suggested

A new predicted geographic distribution was made for each species at each of three new values for the climate parameters, assuming that the species would be lost from any presently occupied square that moved outside the climate envelope The proportion of squares 'lost' is an estimate of the vulnerability of the species to that particular change

This was a 'worst-case' method, measuring the extent to which 'losers' might lose It does not assess how many new squares might become available to a rare species, ie how much potential 'winners' might win



Mean annual temperature
10 km squares averaging >13 5°C (■) indicate the warmest parts of UK, the coldest (<10 5°C) are indicated by a dot



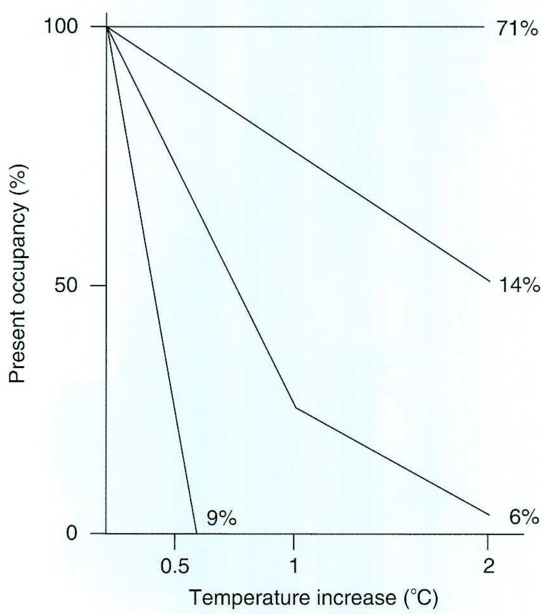
Continentality
10 km squares having >20 °C difference between mean July maximum and mean January minimum temperatures are indicated by ■ and the least continental areas (<15 5 °C) by a dot

Five climate change scenarios described by combinations of three new values of rainfall, continentality and annual mean temperature

An increase of 2°C in annual mean temperature is the best prediction for the year 2040, and could induce a change in continentality ranging from −1 to +3°C and in rainfall from −100 mm to 200 mm, approximately −10% to +20%, being the range of uncertainty predicted for a 2°C rise in mean temperatures

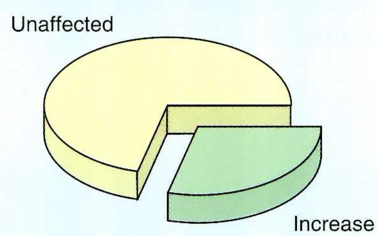
Scenario change in	Mean rainfall	Continentality	Mean temperature
Wet, milder winters	+200	−1	+0 5
Dry summers and wet winters	+100	0	+1
Warm, wet summers	0	+1	+0 5
Hot, dry summers and colder, wet winters	0	+3	+0 5
Generally warmer and drier	−100	0	+2

The proportions of British *RDB* species showing different patterns of predicted distribution loss for different increases in annual mean temperatures

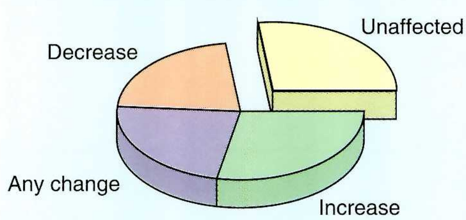


The proportions of British *RDB* species predicted to be vulnerable to distribution loss if:

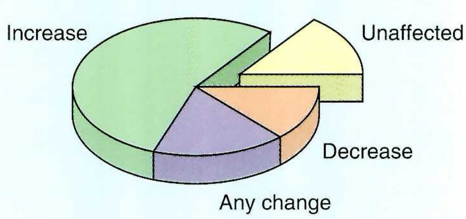
i. temperature changes



ii. continentality changes



iii. rainfall changes



The predicted loss of distributions of individual *RDB* species was used to estimate the impact of the components of climate change. Species recorded in less than nine 10 km squares were excluded to avoid overestimating sensitivity to change, leaving 279 species. The responses tended to cluster around distinct patterns, allowing some generalisations to be made.

For example, using three possible values for mean temperature increase, the species were grouped around four distinct patterns (left). With a 2°C rise, 71% of species were predicted as showing no loss of distribution, while 14% may be reduced to half their current extent. The remainder were severely threatened.

All five of the climate change scenarios used predicted only an increase in mean temperatures. However, one forecasted reduced rainfall and another decreased continentality; therefore, for these parameters the distribution loss was investigated for both increased and decreased values, and six clusters of species response were produced in each case. There were 144 ways in which the response patterns to the three climate parameters could be combined, but five of these combinations described the responses of 251 species, or 90% of those recorded in more than eight squares. The five combinations can be summarised describing species that are **unaffected, south-eastern dry, continental, northern humid or south-western humid**.

Unaffected

No response to the projected changes in any of the three climatic variables was predicted for 56 of the 251 species (about 22%). These were all widespread in Britain, having been recorded in an average 70 squares, and were unlikely to be restricted climatically. They should not suffer directly from any of the climate change scenarios for Britain. However, many were included in *RDBs* for other reasons than a restricted range, such as habitat vulnerability, and could be harmed by indirect consequences of climate change, eg changed land use.

South-eastern dry

The same proportion (22%) of the species were associated with the drier conditions of eastern England; 95% of all records for this group were south of a line joining the Humber and the Severn. Their generally more restricted distribution than the unassigned group was reflected by the generally fewer squares with records. This group of species was likely to be vulnerable only to a significant increase in rainfall in southern England.

Continental

The largest group (40% of species) was clearly associated with a most continental type of climate. Nearly all records were east of a line due north from Dorset, and many were restricted to south of the Wash. They will be unaffected by increased temperatures but could decline either if rainfall increases or if continentality decreases. Many *RDB* animals were in this group, which may include many 'winners', if Britain were to become significantly hotter and drier.

Northern humid

A group comprising about 12% of species had a north-western distribution, most of the 30 species living in central Scotland and the remainder in Wales and Cornwall. These should be affected in almost the opposite way to the continental group. They would be expected to show a reduced distribution if rainfall decreased or climate, particularly winters, became milder.

South-western humid

A small number of species (<5%) formed a group that was expected to suffer if rainfall and continentality decreased. It included a subset restricted to the extreme south-west and the warmest parts of the south coast, which, providing conditions remained humid, might even benefit from rising temperatures.

Of the 28 species that could not clearly be assigned to one of the five groupings, a small subset, comprising six plant species, was characterised by having very 'tight' geographical distributions, which were probably limited more by factors such as geology than by climate.

Number of British *RDB* species, recorded in more than eight 10 km squares, found in each of the major response categories

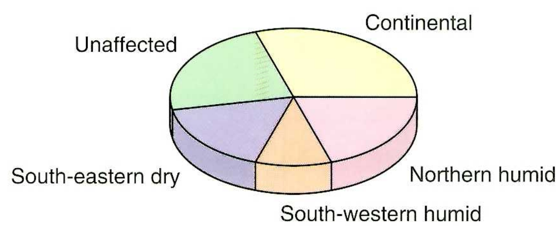
	Plants	Invertebrates	Vertebrates
Unaffected	31	14	11
South-eastern dry	40	12	2
Continental	47	51	2
Northern humid	23	7	0
South-western humid	9	2	0
Unassigned	22	5	1

The groups established for species recorded in more than eight squares were extrapolated to the other species by visual inspection of their recorded distribution. A much larger proportion of species recorded in less than nine squares appeared to belong to the northern humid or south-western humid groups (below).

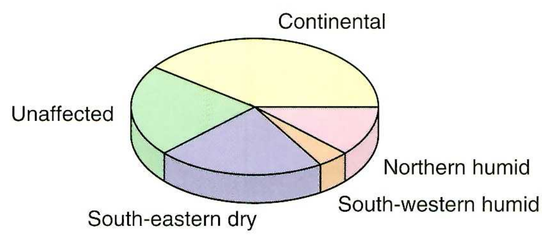
Overall, 23% of Britain's *RDB* species were unlikely to be directly affected by any of the climate change scenarios, and the 47% in the south-eastern dry and continental groups would be threatened if rainfall increased significantly. Conversely, of the 30% which would suffer if rainfall decreased significantly, about 20% were in the northern humid group, some of which might also be threatened by warmer winters. The other 10% formed the south-western group of species that might tolerate warmer but not drier conditions, but might suffer if the local climate became any wetter.

The proportion of British *RDB* species in the different response categories

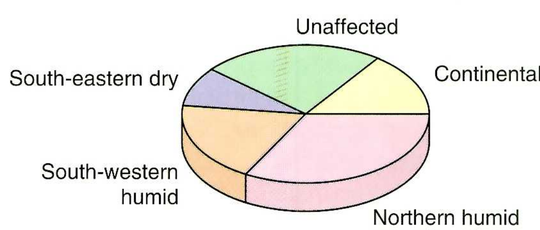
All species



Species recorded in more than eight squares

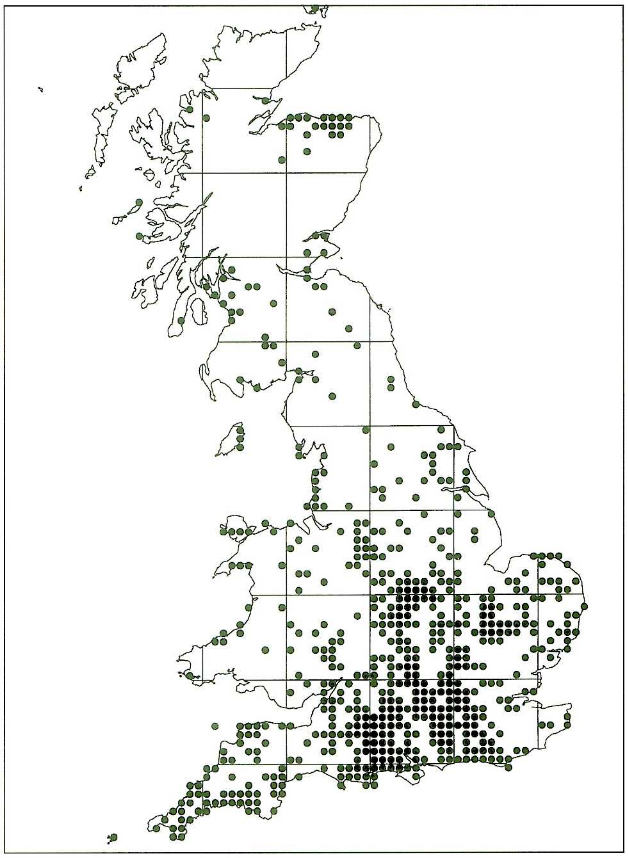


Species recorded in less than nine squares



Examples of *RDB* species unlikely to be harmed by climate change (unaffected group)

Corn cockle (*Agrostemma githago*)



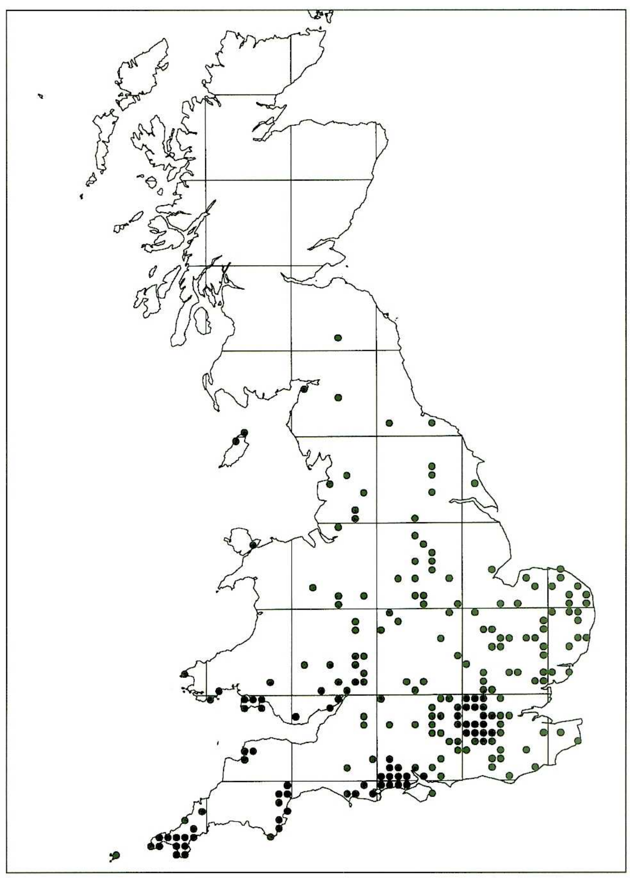
(photo J O Mountford)

The corn cockle is an *RDB1* ruderal species that lives in disturbed land, particularly cornfields. It is believed to be Mediterranean in origin but is now widespread in temperate regions where it tolerates a wide range of combinations of temperature and rainfall. Its decline in Britain is mainly due to habitat loss and herbicidal 'weed control'.

Penny-royal (*Mentha pulegium*)

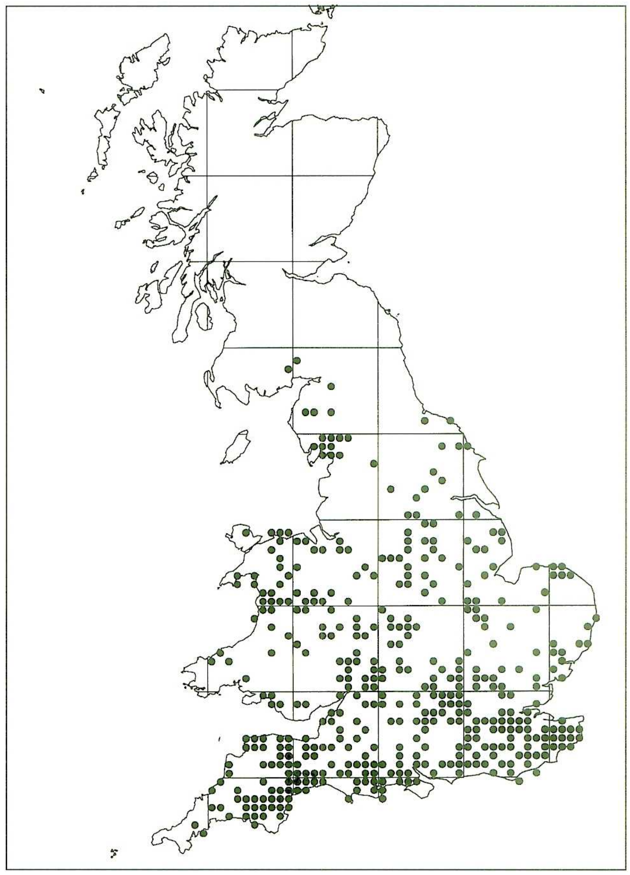
(photo J O Mountford)

Penny-royal is an *RDB2* competitive species It lives by pond margins and wet places, particularly on sandy soil. Found in southern and central Europe, it is unlikely to be harmed by climate change unless increased drought threatens its remaining habitats. Increased land drainage has been the main cause of its recent decline.



High brown fritillary (*Argynnis adippe*)

(photo J A Thomas)



Colonies once bred in woodland glades (below) and warm, rough pasture throughout southern Britain.

(photo J A Thomas)

The species has *RDB2* status because reduction in the coppicing of woodlands resulted in habitat loss. Increased shading in uncoppiced woods is harmful because its caterpillars require a ground temperature of 35°C for optimum growth. Its need for warmth suggests that it may well expand its distribution if spring and summer become warmer.

Egg – laid singly

Larva – feeds upon various violet (*Viola* spp.) species

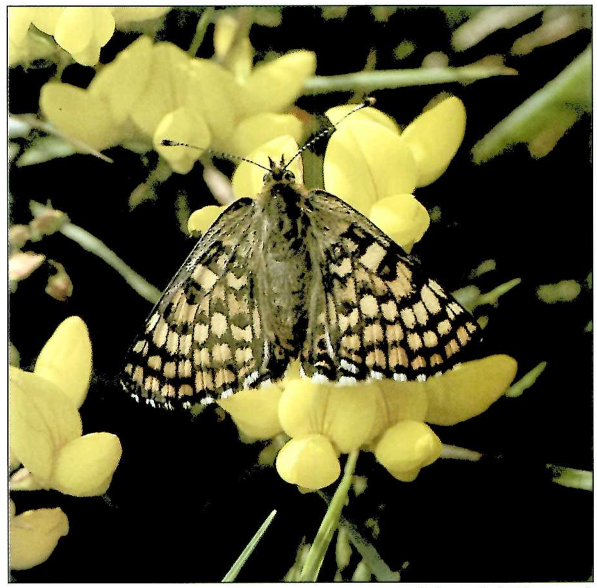
Pupa

(photos J A Thomas)

Examples of species likely to be affected by a significant increase in rainfall in southern England (south-eastern dry group)

Glanville fritillary (*Melitaea cinxia*)

This butterfly is an *RDB3* species, currently restricted to a few exceptionally warm locations on the southern undercliffs of the Isle of Wight. It is well adapted to continental conditions and is abundant further south in Europe. Under a warmer climate, any meadow containing abundant plantains can support a population of Glanville fritillaries.



(photo J A Thomas)

(photo J A Thomas)

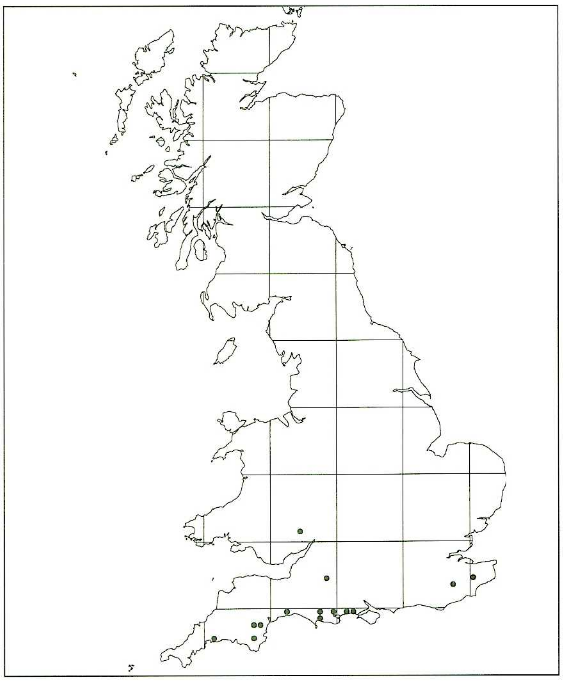
Although predicted to suffer if rainfall increases, the Glanville fritillary is an example of a species that might benefit from warmer conditions. These would permit it to spread into disturbed land, of any aspect, providing plantains remained abundant.

(photos J A Thomas)

The eggs are laid in groups. The larvae cluster together on their plantain foodplant.

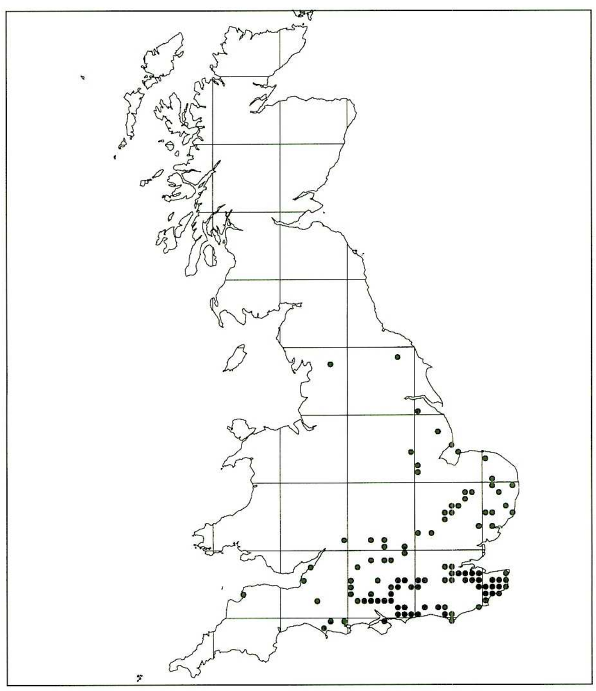
Acrid lobelia (*Lobelia urens*)

Acrid lobelia is an *RDB2* species that is considered to be a stress-tolerator. It is a Lusitanian species of damp heathland and meadows. It appears to be at the northern end of its range in Britain. There is no obvious reason for its scattered distribution along the south coast of England and why it might be vulnerable to increased rainfall.



(photo J O Mountford)

(photo J O Mountford)



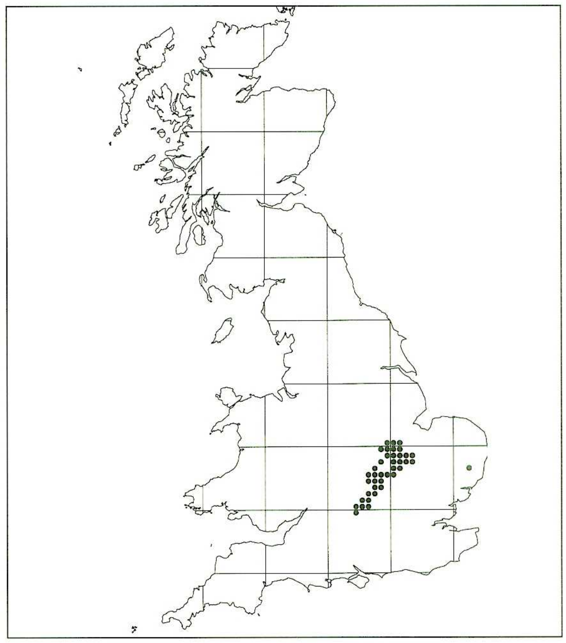
Lizard orchid (*Himantoglossum hircinum*)

The lizard orchid is an *RDB2* stress-tolerant species found in grassland, especially the chalk and limestone grasslands of southern England. Its recent decline has been mainly due to habitat loss through changing land use. Increased rainfall could be detrimental if it promoted the growth of grass or other competitive species.

Examples of species associated with a continental climate in Britain

Black hairstreak (*Strymonidea pruni*)

(photo M J Skelton)



The black hairstreak butterfly is an *RDB3* species associated with the relict woodlands of the east Midlands. It needs over-grown sunny glades with blackthorn (*Prunus spinosa*) (below) – the larval foodplant, and is threatened, currently, by the loss of long-term coppice management of woodlands. The distribution analysis indicates that this species could suffer if south-east England became wetter and less continental but it could benefit from warmer drier conditions. Such conditions are most probable if a more continental Britain resulted in the abandonment and 'scrubbing' of grassland; however, it might be slow to take advantage of any habitat expansion because it is relatively sedentary and a slow coloniser.

(photo J A Thomas)

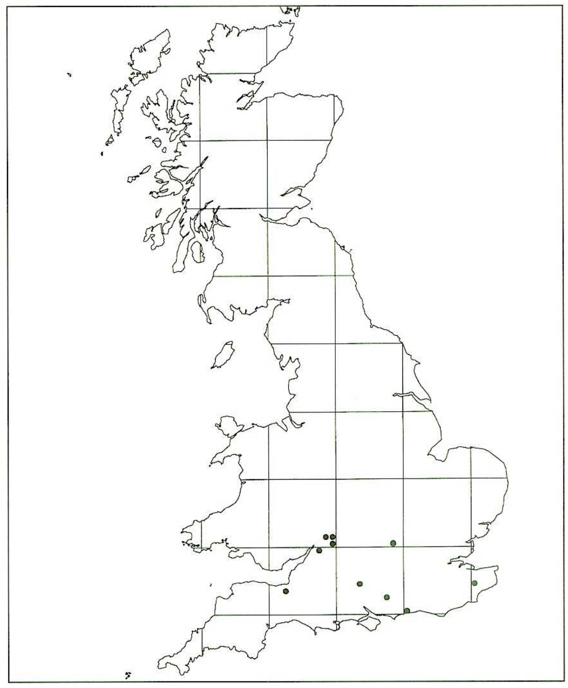
Larva – difficult to find

(photos J A Thomas)

Pupa – well camouflaged as a bird dropping

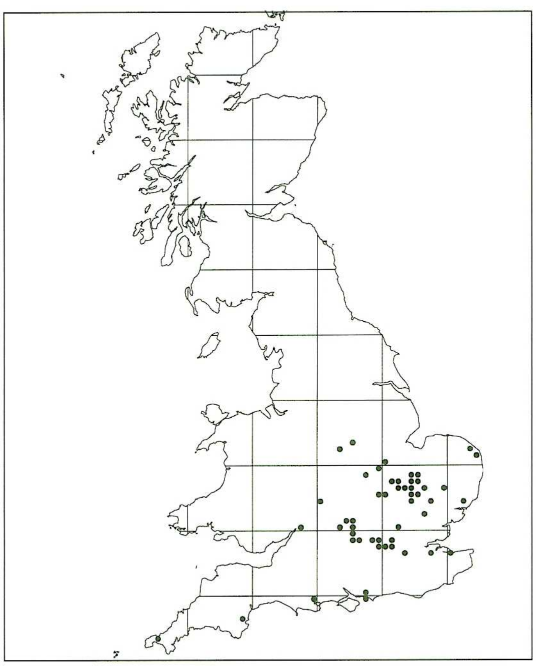
Red helleborine (*Cephalanthera rubra*)

(photos J O Mountford)



This orchid is an *RDB1* stress-tolerator that grows on limestone and chalk. It is associated with beech (*Fagus sylvatica*) woods in southern England, particularly near to the Severn valley, an area that has cold winters and warm summers. It is pollinated by small bees that might have a restricted distribution.

Grass poly (*Lythrum hyssopifolia*)



(photo J O Mountford)

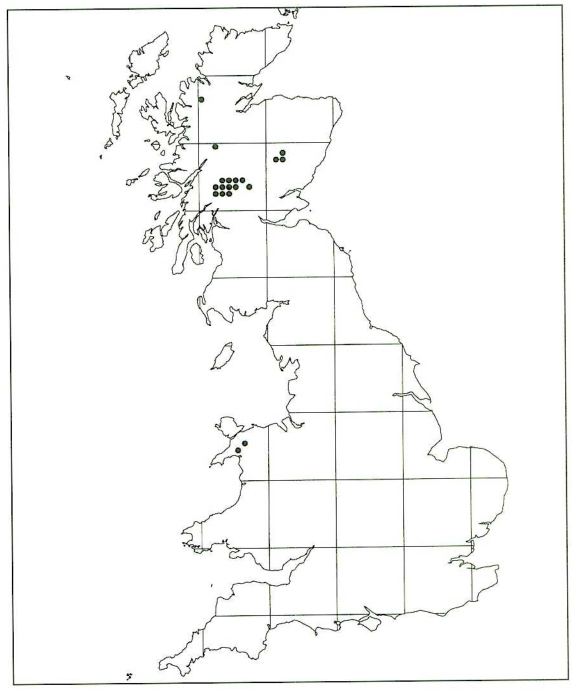
Grass poly is an *RDB2*, ruderal species also found in south and central Europe. It is believed to be native in south-east England but introduced elsewhere. It grows in open areas having winter flooding. It might suffer if winter rainfall is reduced or summer droughts increase, but could benefit from increased warmth.

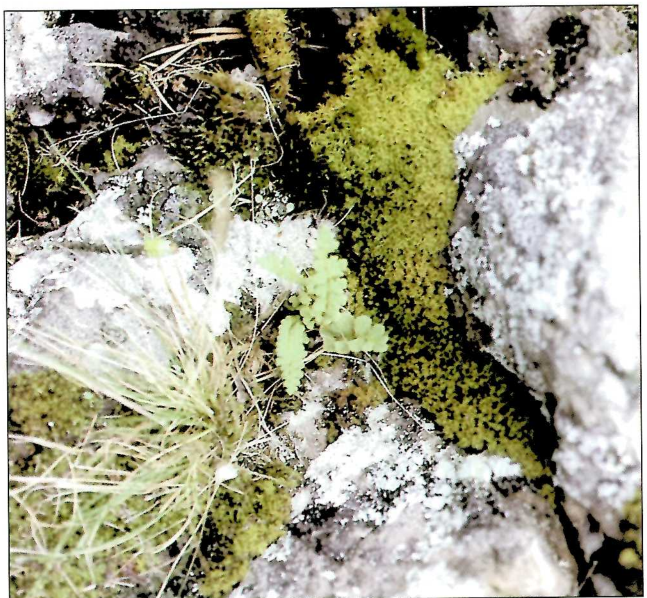
Examples of species in the groups having humid distributions

The analyses grouped together two sets of species that appear to be associated with the high rainfall conditions of western Britain, called the **northern humid** and **south-western humid** in this report. They include a mixture of species that require humid conditions – Lusitanian species at the northern edge of their range in Britain, and others, basically alpine species, which are restricted to the west of Britain by topography.

Alpine woodsia fern (*Woodsia alpina*)

This *RDB3* species is an arctic-alpine limited in Britain to damp rock crevices in mountains. Most British records are from the central Highlands of Scotland. It occurs from Scandinavia through northern Russia and in high mountains in southern Europe. It would probably suffer some losses from a warmer climate, particularly if this resulted in drier conditions.





(photo J O Mountford)

Tufted saxifrage (*Saxifraga cespitosa*)

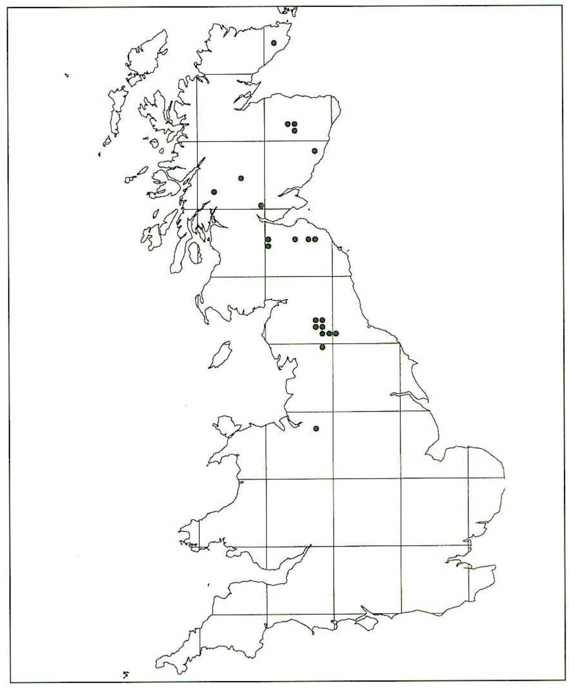
Outside Britain, this *RDB3* species has an arctic circumpolar distribution. Its British distribution is very similar to the alpine woodsia fern. It is a good example of a species that might be harmed directly if temperatures became significantly warmer.

(photo J O Mountford)

Marsh saxifrage (*Saxifraga hirculus*)

This arctic-alpine saxifrage has a more widespread distribution in the north of Britain and worldwide ranges from the Himalaya to the Rockies. It is classed as *RDB3* and lives on wet, acid soil. It is probably most at threat from warming if this results in greater drying out of soils.

(photo J O Mountford)



Examples of species with south-western humid distributions

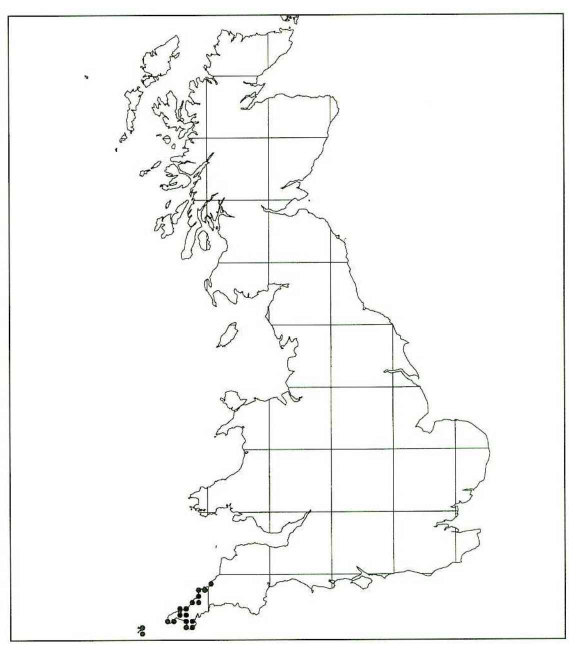
Sea knotgrass (*Polygonum maritimum*)

(photo J O Mountford)

This *RDB1* species is an example of a Lusitanian–Mediterranean species that reaches its northern limits in Britain. Like a number of similar species restricted to the extreme south-west of England, it lives on coastal sands and shingles where winter temperatures are warmest. It may be at risk from reduced coastal rainfall, but could benefit from increased temperatures.

Western ramping fumitory (*Fumaria occidentalis*)

This *RDB3* species is endemic and is restricted to coastal areas of south-west England, where it grows in open, disturbed places. It is not known if its restricted distribution is dependent upon the mild, humid climate of the south-west or upon other factors. It may suffer if conditions became less humid.



Climate and breeding bird populations

The numbers of all species of birds with less than 300 pairs breeding in Great Britain and Northern Ireland are assessed and published each year by the Rare Breeding Birds Panel (reference 7). These data are obtained by the voluntary efforts of hundreds of ornithologists and constitute one of the best data sets on populations of rare species. Even so, the run of data is relatively short, being first published in 1973.

The British Trust for Ornithology undertook an analysis of these data in relation to annual variations in weather to investigate whether any trends between weather conditions and breeding numbers could be established. It was assumed, for example, that any species that did better in warmer years might flourish if global climate change produced a warmer climate in Britain.

Weather data were averaged over the geographical distribution of each species. The number of possible weather variables was reduced to three – mean temperature, rainfall and days of frost, for five key periods preceding the breeding season. The data set was then investigated statistically to highlight any correlations between bird numbers and the weather variables.

There were considerable variations between individual species, suggesting that weather patterns affected most species in unique ways. However, there was a clear trend for the numbers of many of the breeding species to be greater in seasons following increased rainfall. Frosts also appeared to have a beneficial effect on some species but most showed no benefit in years with increased average temperatures.

Breeding species that overwintered in Europe showed the most response to weather. Fifteen of the 26 species investigated appeared to do better when seasons were wetter than average. There were about equal numbers of species that could be categorised as being land or water birds and breeding in the north or south of Britain (below). Generally, the relationships between rainfall and breeding numbers were stronger for water birds compared to land birds, and for southern breeding species *versus* northern species.

Eighteen species that overwinter in Africa showed very few relationships between weather in Britain and the numbers of breeding pairs, although some did better after periods of higher rainfall in North Africa.

Redwing (*Turdus iliacus*)

(photo British Trust for Ornithology)

Bittern (*Botaurus stellaris*)

(photo British Trust for Ornithology)

Species showing most response to rainfall

Northern species

Water birds	Pintail, goldeneye, whooper swan, black-necked grebe
Land birds	Purple sandpiper, redwing, scarlet rosefinch

Southern species

Water birds	Pintail, Mediterranean gull, little gull, bittern
Land birds	Cirl bunting, serin, Cetti's warbler, firecrest

Interpretations from the analyses of rare breeding birds

The generally beneficial effect of rainfall on rare breeding birds, especially residential species, is paradoxical at first sight. It is generally believed that rainfall is detrimental, interfering with feeding and wetting plumage. However, rainfall may promote the production of seeds and invertebrates, so improving food supplies for birds.

Other species that showed specific relationships with weather

Overwintering in Europe
Slavonian grebe, scaup, red kite, goshawk, Dartford warbler, brambling, lapland bunting

Overwintering in Africa
Garganey, honey buzzard, hobby, Temminck's stint, ruff, wryneck, hoopoe, Savi's warbler

These 15 species had various strong specific relationships with some aspect of weather, but most were difficult to interpret. The Dartford warbler showed a very clear relationship between numbers and mean temperatures, which was expected for a species at the northern edge of its range in Britain.

The overall inference from the analyses was that increased temperatures, providing summer rainfall was maintained, would benefit about one third of our rare breeding birds, but, if drier conditions result, especially greater frequencies of summer droughts and cold wet winters, then climate change would harm about half of our species.

Dartford warbler (*Sylvia undata*)

(photo B Pearson)

Fifteen species showed no detectable relationships with weather

Overwintering in Europe
Red-necked grebe, common scoter, avocet, fieldfare

Overwintering in Africa
Black redstart, marsh and Montagu's harriers, osprey, spotted crake, stone curlew, black-tailed godwit, wood sandpiper, red-necked phalarope, golden oriole and red-backed shrike.

Brambling (*Fringilla montifringilla*)

(photo J Marchant)

Brambling has a generally unclear response to weather but seems to do better in wetter years.

Numbers of rare passage birds were also examined in the same manner because some could become British breeding birds following climate change. This group of species showed many relationships with weather, the strongest being with days of frost, but none were sufficiently clear-cut to be able to suggest the causal connections or to make generalisations. The main variations may be determined not by climate over a period of months, but by weather, especially patterns of winds, over brief but critical periods during migrations.

Permanent lowland grasslands support a plagioclimax vegetation, that is a community maintained at an intermediate successional stage by management. Grassland is subjected to various combinations of stress and disturbance (right). Individual plants living in short swards suffer high stress because of exposure to the dehydrating effects of wind and sun. Grazing, which normally maintains the short turf, causes different amounts of disturbance to different species. All plants living in taller swards experience much disturbance when they are burnt or mown, and a short period of high stress, mainly due to soils drying out, following such management.

Long-term community studies by NERC's Unit of Comparative Plant Ecology compared a tall sward on a roadside at Bibury and the shorter-turfed chalk downland of Aston Rowant National Nature Reserve, and confirmed that stress-tolerant and ruderal plants were favoured over competitors in normal years. At Bibury the selection against competitors became even more marked in hot, dry summers which created both additional stress and disturbance, causing the death of some plants. Conversely, competitors were promoted in normal summers following mild winters.

Intensive grassland management can counteract the effects of climate change
Summer weather had little effect on the plant community of Aston Rowant, because any tendency for selection for or against competitor species was automatically eliminated by managers who adjusted stocking rates to match the vegetative production. Stocking rates were always low in winter, even though mild winters encouraged plant growth, permitting the animals to graze selectively on palatable species, which tended to be ruderals. This favoured stress-tolerant competitors at the expense of competitive ruderals.

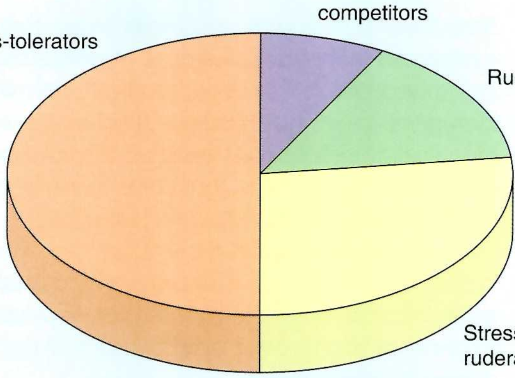
THE CONCEPT OF PLANT

Environmental factors that affect individual plant growth, production and, ultimately, survival are considered to produce 'stress' or create 'disturbance'. Stress is caused by factors that place prior restrictions upon production, eg inadequate amounts of light, heat, nutrients or water. Disturbance is caused by a variety of natural and anthropogenic phenomena that partly or totally destroy vegetational biomass, once it has grown. Plants evolving under conditions of minimal stress and disturbance are good competitors (C). Some species evolved mechanisms to tolerate stress (S) while other, ruderal species, evolved to cope with high disturbance (R).

Sheep grazing in winter

(photo L K Ward)

Half Britain's *RDB* plants are stress-tolerators



A large proportion of the remainder were stress-tolerant ruderals. Most rare and endangered plants in Britain are specialised to live in conditions of high stress, resulting in niche specialisation. This restricts their range; for example, a species evolved to tolerate both drought and high alkalinity is unlikely to survive in dry but acidic biotopes. A smaller, but significant proportion were ruderals, adapted to high disturbance.

'UNCTIONAL TYPES (reference 2)

No plants have evolved to tolerate both maximum stress and maximum disturbance. Therefore, it was possible to assign plant responses to stress and disturbance in a triangular space, bounded by the three main functional types, known as the C–S–R model. Research at NERC's Unit of Comparative Plant Ecology (UCPE) has determined the functional type of much of the British flora, including many of the *Red Data Book* plant species. This enables botanists to infer the probable response of those species under different types of stress and disturbance scenarios.

The main conclusion of the UCPE analyses was that the prognosis for Britain's *RDB* plants, based upon functional types, depended upon the extent to which winters became warmer and summers relatively drier. If winters became much milder and summers remained moist, then competitive plants, which tended to be the more abundant common species, should be promoted at the expense of many of our *RDB* species. On the other hand, if summers were to become drier, with periods of drought, then many of the southerly *RDB* stress-tolerating species might actually do better. However, habitats of many stress-tolerating *RDB* plants included biotopes that had already experienced the greatest previous change in species abundances, and were considered most vulnerable to future anthropogenic changes. This gave the complicated prediction that: **climate change which increases stress could benefit many individual stress-tolerating *RDB* plants but threaten the community structure in which they live.**

Aston Rowant NNR

1980 with 'animal exclusion plot' behind the fence in the background

(photos L K Ward)

1986 Note the increase in scrub cover of the exclusion plot, during the intervening years

Potential winners: the problem of habitat availability

It is often thought that warmer conditions will benefit some species, particularly those at the northern edge of their ranges. However, the ability of such species to take advantage of such changes is likely to be severely limited by other factors, such as the availability of suitable biotope. Consideration of two rare butterfly species illustrates this problem.

The Adonis blue butterfly (*Lysandra bellargus*) is scarce in Britain, although it is not included in the national *Red Data Book*. It has declined greatly in recent years and now occurs at about 100 sites, only a small fraction of the number it occupied in the first part of this century.

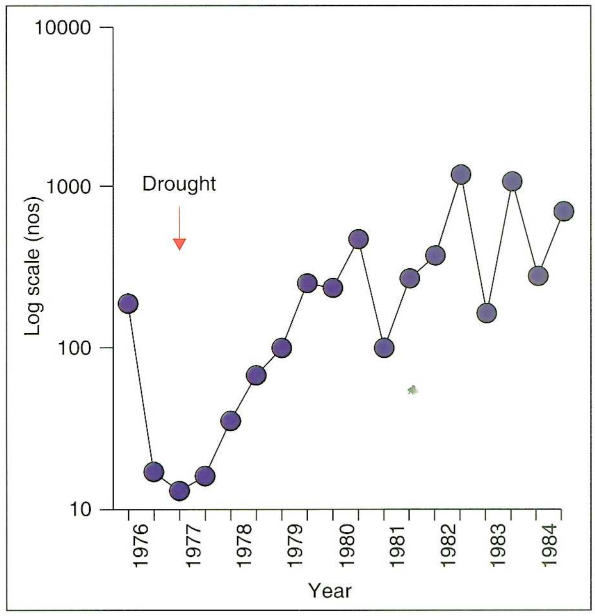
Its larvae feed on horse-shoe vetch (*Hippocrepis comosa*) growing in the warmest conditions. The best populations all live on well-grazed, south-facing hillsides where the exposed soil is in full sun. It is protected from predators and parasites by ants which it rewards with sugary secretions.

(photo J A Thomas)

The Adonis blue has declined because changing land use has reduced the number of sites having suitable open short turf, causing it to become restricted to the hot south-facing slopes. One might expect that this butterfly would greatly benefit from increased summer temperatures as populations expand into slightly cooler sites, such as the tops of downlands. However, in practice, many of these sites no longer exist as flower-rich grassland having been ploughed or fertilized. Consequently, populations may remain restricted to the south-facing slopes.

South-facing grassland slopes are particularly prone to suffer when hot, dry summers produce periods of drought. Populations of Adonis blue can crash during severe drought. If climate change increases the frequency of summer drought, then populations Adonis blue might suffer rather than benefit from the increased warmth.

Changes in numbers of Adonis blue recorded from a hot hillside in Dorset



The large blue butterfly (*Maculinea arion*) is an example of a species restricted indirectly by climate in Britain. This *RDB1* species was once fairly common on the downs of southern England, but it became extinct in 1979. It has a most unusual life cycle. It lays its egg on the common thyme (*Thymus drucei*) plant where the caterpillar feeds on the developing flowers. While it is a small caterpillar, it must be 'adopted' by a nest of red ants (genus *Myrmica*). It lives for ten months inside the ant nest, preying upon the ant grubs, and even pupates inside the nest.

It was shown that the large blue depends upon just one species of red ant. Colonies of the butterfly only persisted on sites having large populations of the host ant, *M.sabuleti*, which is a thermophile. Populations declined because a reduction in grazing by sheep and rabbits resulted in longer turfed, cooler grasslands that supported inadequate populations of *M.sabuleti*. Management of some sites for short turf has enabled the species to be reintroduced into England.

(photo J A Thomas)

If global warming raises the soil temperatures of less well-grazed grassland to the levels previously found only in the shortest turf, then populations of *M.sabuleti* should increase once more, and the large blue could spread to many of its former sites. In the meantime, suitably warm conditions must be maintained by intensive management.

However, it faces the same short-term problems of habitat availability as the Adonis blue. Also, its small isolated populations are vulnerable to drought – the last British population was lost as a result of the 1976 drought. The extinction of the British large blue provides two lessons: first, how a population reduced to dangerously low levels through anthropogenic factors can be lost as a direct result of freak climatic conditions and, second, the high costs of reintroduction compared with the estimated cost of conservation, had research into site management been undertaken earlier.

A former site for *Maculinea arion* that became slightly too overgrown to support *Myrmica sabuleti*

(photos J A Thomas)

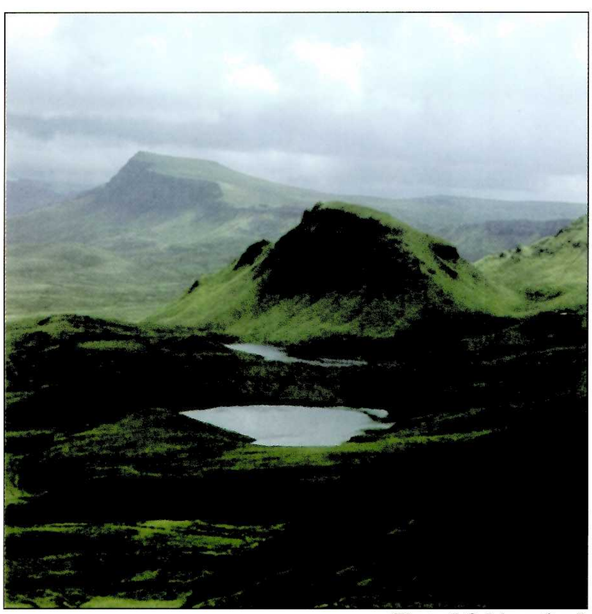
Short open turf, ideal for both *Myrmica sabuleti* and thyme, that could support a population of large blue butterflies under present climatic conditions

The same turf in a year of severe drought

Conservation of *RDB* species under climate change

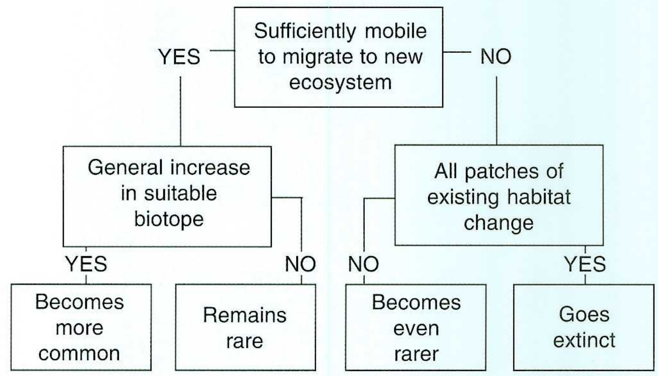
The study has concentrated on the negative consequences of change (right-hand side of Figure) in an attempt to identify those *Red Data Book* species that might become extinct or even rarer, under particular climate change scenarios. Future patterns of rainfall will have the greatest effect upon the distribution of rare species. If Britain develops a generally more continental climate with drier, hotter summers and little change in winters, then many rare western and northern montane species might suffer, but many species that depend upon warm biotopes in an early seral stage might benefit. Probably the least damaging scenario for most *RDB* species is wetter, milder summers and winters in Scotland, combined with more continental conditions in southern England.

Throughout earth's history, plants and animals either have adapted to climatic changes or tracked suitable climatic regions. Our understanding of previous change suggests that speciation and extinction events normally take place over a timescale of 100 to 1000 generations (most generation times ranging from one to 100 years). Existing species need between ten and 100 generations to fix adaptations to change. The present problem is that climate is expected to change significantly during the next one to 100 generations of most species. While this might not be unprecedented, when it is combined with man's modification and destruction of natural biotopes, the effects might be unprecedented. There is no reason to suppose that speciation and evolution of most taxa will occur more rapidly than previously; consequently it is believed the immediate effect will be an increased extinction rate.



(Photo J O Mountford)

Possible outcomes for rare species



The short-term response to predicted climate change will be modifications of individual phenology or behaviour, combined with adaptability of the population dynamics. For example, the British race of the large blue butterfly was a poor disperser, but recent evidence suggests that poor dispersal is an adaptation acquired over the last 100 years (generations), enabling it to persist in an increasingly fragmented and isolated habitat. Factors such as individual mobility, migration and metapopulation processes will determine which species survive the change and which fail. These are also the levels at which conservationists can operate. If biotope management can mitigate the impact of change on particular populations, new patches of habitat can be created for species or groups of species which can be translocated.

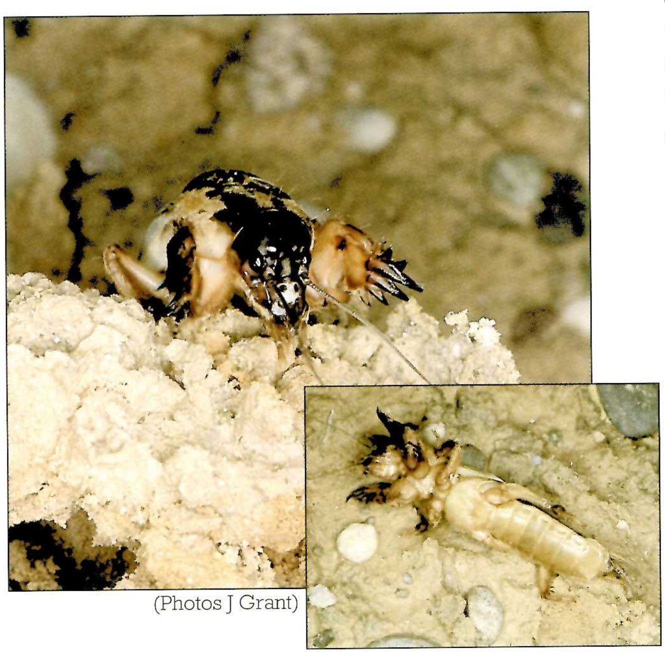
The UCPE analysis suggests that intensive management, such as the careful regulation of grazing regimes, could counteract the short-term effects of climate change on habitats with plagioclimax vegetation, such as chalk grasslands. However, this option is unlikely to be available for natural climax or more mature, less intensively managed biotopes, such as ancient woodland.

Also, it is probable that very little can be done to aid the arctic and alpine *Red Data Book* species that have very restricted distributions in the mountains of Scotland and Wales (left). If they are limited directly or indirectly by temperature, then their only salvation would be to move further up into the mountains. In many cases, the species do not have the behavioural adaptations necessary for rapid spread into new habitat, perhaps because they have evolved non-mobility in response to isolated but stable habitats. It might be possible to translocate species into new habitat, providing that it can be identified, but for the most part it must be accepted that many of these species might eventually be lost from Britain.

On the other hand, rare species at the northern edge of their range might benefit from a 2°C warmer climate, particularly if they are limited by temperature. If new potential habitat forms as existing biotopes change, the problem might become one of maintaining populations in existing sites for long enough, before the new habitat becomes available. For example, if we wished to maintain a population of *M.sabuleti* on a particular site in a 2°C warmer Britain, then the grass should be allowed to grow taller. However, the resulting grassland plant community produced by warmer conditions and a different management regime might be very different from the original community. This could create a conflict of interests between different managements for different species in threatened biotopes. The greater the climate change, the more such conflicts could occur.

In the long term, many populations of rare species will survive only if they can become established in different areas of biotope that contain suitable habitat requiring minimal management effort, beyond that which is required to maintain the community. If, nationally, we wish as many as possible of our rare species to survive climate change, conservationists might have to be much more actively interventionist than hitherto. Wherever possible, existing populations should be managed to provide stock for introductions. Then, when new populations are established and self-maintaining, the management can cease and nature can be left to take its course.

Mole cricket (*Gryllotalpa gryllotalpa*), an *RDB1* species on the British list, *in situ* and from underneath showing the strong digging feet



(Photos J Grant)

If the translocation of endangered species is acceptable on regional and national scales, then should such measures be considered from a European perspective? It can be argued that, if man had not so fragmented natural biotopes, possibly causing selection for restricted mobility by many species, a generally warmer northwards climate should have resulted in some of these species reaching Britain. Although the semi-natural or traditional cultural biotopes of southern Britain have been reduced and fragmented (reference 8), they still form quite a large proportion of those which remain in mid-latitude western Europe. Britain will have areas where, under a warmer climate, continental European species threatened on a global scale could thrive. A dilemma will be to what extent Britain should meet international obligations by introducing into potential sites endangered European species that are not part of the present British flora and fauna.

Maculinea alcon **- globally endangered *RDB* species which could be successfully introduced into a warmer Britain**

(Photo J A Thomas)

A marsh in France that supports two of the world's rarest butterflies, the mole cricket and a rare species of red ant. All could thrive in similar places in a warmer southern England.

(Photo G W Elmes)

References and recommended reading

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Some ecological terms used in this booklet

Biotope A biotope is a concept rather than a real entity, it is defined subjectively by a range of geophysical conditions and the community of plants and animals that it supports Once described, biotopes can be ranked and ordered in a way analogous to species

Community A community is a group of plants and/or animals that live together, they are influenced by the same factors and may influence each other Normally the definition of any particular community is restricted – spatially, biotopically or taxonomically

Continentality The ranges of many species are limited by climatic factors Continentality and its inverse oceanicity are important measures of climate, being the relative difference between winter and summer weather On a scale of 0–100, a score of 100 occurs in parts of Siberia, whereas Britain has an oceanic climate averaging a score of 10

Distribution The distribution of a species is that part of its range where individuals have been recorded, and it is often restricted by anthropogenic factors

Ecosystem An ecosystem normally encompasses all the physical and biotic factors that affect organic life within a geographically defined area An ecosystem may contain areas of many different biotopes that provide habitat for plants and animals

Habitat At an individual level, habitat is the living space of the individual which, in the case of most animals, may encompass several different biotopes At the species level, habitat is described by the range of biotopes in which that species normally lives

Plagioclimax A plagioclimax is the climax condition achieved when a natural succession has been diverted into an alternative stable state by regular application of anthropogenic or man-made factors, such as burning, grazing, mowing and coppicing

Range The range of a species is the geographical area within which environmental conditions permit individuals to survive

Succession Most biotopes pass through a series of developmental stages, referred to as natural succession, that end when a stable or climax condition is reached

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The **INSTITUTE OF TERRESTRIAL ECOLOGY** (ITE) is one of 15 component and grant-aided research organisations within the NATURAL ENVIRONMENT RESEARCH COUNCIL (NERC) Its six research stations, spread throughout Britain, provide ready access to environmental and ecological problems at any site in the country This, combined with the expertise of the staff and the facilities at the research stations, enables the Institute unparallelled opportunities for long-term multidisciplinary studies of complex environmental and ecological problems

The **BIOLOGICAL RECORDS CENTRE** (BRC) is part of ITE's ENVIRONMENTAL INFORMATION CENTRE (EIC) It is jointly supported by NERC and the Conservation Agencies through the Joint Nature Conservation Committee BRC's computer data base now contains over 6 million records of some 10 000 species and is a major resource for any research concerning Britain's wildlife

The **UNIT OF COMPARATIVE PLANT ECOLOGY** (UCPE) is part of the Terrestrial and Freshwater Sciences Directorate of NERC It maintains an integrated approach to the study of vegetation and plant distributions, combining field survey with laboratory screening for physiological, cytological and biochemical characteristics

The **BRITISH TRUST FOR ORNITHOLOGY** (BTO) is part of the National Centre for Ornithology at Thetford, Norfolk It has access to large numbers of national and regional records for British bird populations BTO scientists undertake work on all aspects of bird ecology, distribution and behaviour

Global warming is likely to change the climate of our world during the next century.

It is predicted that within 50-100 years the UK might be generally 2°C warmer and, in Scotland, winters might even be 4°C milder. Such an increase is sufficient to affect all aspects of land use – farming, forestry, industry, recreation and nature conservation – and, directly or indirectly, harm many of our rare plant and animal species. It is important to consider this possibility now. Which species are at most risk? How can we mitigate the effects to ensure their survival?

This booklet summarises research into the probable effects of climate change on the distributions of rare species, its possible effects upon the natural communities of our permanent grasslands, and its impact upon the breeding success of rare birds.

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