



Modelling potential impacts of climate change on the bioclimatic envelope of species in Britain and Ireland

P. M. BERRY, T. P. DAWSON, P. A. HARRISON and R. G. PEARSON

Environmental Change Institute, School of Geography and the Environment, University of Oxford, 1A Mansfield Road, Oxford OX1 3SZ, U.K.

ABSTRACT

Aim Climate change has the potential to have significant impacts on the distribution of species and on the composition of habitats. This paper identifies the potential changes in the future distribution of species under the UKCIP98 climate change scenarios, in order that such changes can be taken into account in conservation management.

Location The model was applied to Britain and Ireland.

Methods A model based on an artificial neural network was used to predict the changing bioclimate envelopes of species in Britain and Ireland. Fifty-four species representing 15 habitats were modelled.

Results The modelled species could be placed into three categories: those losing suitable climate space, those gaining it, and those showing little or no change. When the species were

associated with habitats it was found that Arctic–Alpine/montane heath communities were the most sensitive to climate change, followed by pine woodland and beech woodland in southern England. In lowland heath, wet heath, cereal field margins, coastal grazing marsh, drought-prone acid grassland and calcareous grassland, the species either showed little change or an increase in suitable climate space. The other eight habitats showed a mixed response.

Conclusions The species show a variety of responses to climate change and thus their current habitat associations may alter. The uncertain future of some species and habitats is highlighted. Conservation policy and practice will need to be revised in the face of climate change.

Key words artificial neural network, bioclimate envelopes, Britain, climate change, conservation, habitats, Ireland, SPECIES model.

INTRODUCTION

Much conservation management and policy is focused on species and habitats. This is seen, for example, in the UK response to the Convention on Biological Diversity, which has led to the formulation and adoption of the UK Biodiversity Action Plan, where the emphasis is on the conservation of habitats and species (UK Biodiversity Group, 1999). It is recognized, however, that species and habitats exist in an environment where natural and anthropogenic pressures cause change (Cramer & Whittaker, 1999). One concern is the possible impacts of climate change, such as those projected by the Intergovernmental Panel on Climate Change report (IPCC, 2001). This states that available observational evidence shows that regional changes in temperature have already affected

a range of physical and biological systems around the world. These and projected future changes could have a profound effect on all aspects of species and habitat functioning and distribution (e.g. Bush, 2002; Midgley *et al.*, 2002; Scott *et al.*, 2002). Therefore, it is important that such changes are anticipated so that appropriate adaptation can be taken (Hannah *et al.*, 2002).

Developing models to assess the potential impacts of climate change on individual species distributions is comparatively easy. The parameterized known climatic requirements or tolerances of a species used in the modelling are termed climate envelopes. A number of researchers have used climate envelopes to model the distribution of suitable climate space for individual species (Beerling *et al.*, 1995; Huntley *et al.*, 1995; Sykes & Prentice, 1995; Sykes *et al.*, 1996). It is, however, more difficult to model habitats, which are composed of assemblages of species.

Two recent studies, REGIS (Regional climate change impact and response studies in East Anglia and North-west England) and MONARCH (Modelling Natural Resource Responses to Climate Change), have used an artificial

Correspondence: Dr P. Berry, Environmental Change Institute, School of Geography and the Environment, University of Oxford, 1A Mansfield Road, Oxford OX1 3SZ, UK. E-mail: pam.berry@eci.ox.ac.uk

neural network model, based on bioclimate inputs and the distribution of species, as a first step in the examination of the impacts of climate change on habitats and their component species (Berry *et al.*, 2001a,b). In these projects the species were chosen to represent a habitat on the basis of the following predefined protocol:

- dominant and/or structurally important plant species (i.e. those that by their longevity and persistence affect habitat change and the potential for invasion);
- indicator species and those sensitive to climate (e.g. at range margins); and
- priority (Biodiversity Action Plan — BAP) species; but extremely rare species were avoided as they are difficult to model.

In addition, where possible plants with different life strategies (*sensu* Grime *et al.*, 1988) were included for each habitat, as well as one nonplant species.

This paper uses the results from these two projects, which comprise 54 species representing 15 habitats, and explores some of the consequences for nature conservation.

METHODS

The potential response of species to climate change was ascertained using SPECIES (Spatial Estimator of Climate Impacts on the Envelope of Species), a model that was developed during the REGIS project. The details of the model have been written up elsewhere (Berry *et al.*, 2001a; Pearson *et al.*, 2002), and will be described only briefly here. The SPECIES model was based on an artificial neural network, which integrated bioclimate variables for predicting the distribution of species through the characterization of bioclimatic envelopes. Integrated algorithms including a hydrological balance model were used to preprocess climate (temperature, rainfall and solar radiation) and soils (AWC — available water holding capacity) data to derive relevant bioclimatic variables for input to the neural network. Five variables were used:

- Accumulated annual soil water surplus.
- Accumulated annual soil water deficit.
- Absolute minimum temperature expected over a 20-year period.
- Annual maximum temperature.
- Growing degree days above a base temperature of 5 °C.

The model was trained using existing empirical data on the European distributions of species to enable the full climate space of a species to be characterized and to capture their response to climatic conditions that might be expected in Britain under future scenarios. Observed European distributions were obtained from Hulten (1959), Meusel *et al.* (1965, 1978, 1992) and Jalas & Suominen (1972, 91) for plants; Gasc (1997) for amphibians; Tolman (1997) for butterflies; and Morrison (1992) for mammals. The presence/absence distributions of each species were re-mapped to a 0.5° latitude × 0.5° longitude resolution (to match the climate and soils datasets)

and a kriging interpolation function was applied to provide a smoothed suitability surface. The data were then randomly divided into three groups for training, validating and testing the neural network. A validation set was used to ensure that the network did not over-train on the training data, thus losing its ability to generalize, while the test data were used to provide independent verification of the prediction.

The performance of each network was analysed statistically using the Pearson correlation coefficient and the kappa coefficient of agreement. The kappa statistic was used to test the similarity of spatially mapped data (Monserud, 1990). Once a network was trained, validated and tested at the European scale, it was then used to produce a map of the simulated distribution for current baseline climate and to estimate the potential redistribution of a species under alternative UKCIP98 climate change scenarios. The scenario results were provided as a smoothed 10 × 10-km grid to match the baseline climatology (Hulme & Jenkins, 1998). For the SPECIES modelling the climate data for each 10-km grid square were divided into four equal value quarters, so that they matched the resolution of the soils data.

Four climate change scenarios have been developed for Britain and Ireland on behalf of the United Kingdom Climate Impacts Programme (UKCIP) for three time periods (2020s, 2050s and 2080s) (Hulme & Jenkins, 1998). These scenarios use the output from 'experiments' undertaken with the global HadCM2 Global Climate Model (GCM). The four scenarios reflect uncertainties in future global warming rates attributable to different climate sensitivities and greenhouse gas emissions scenarios. The present paper focuses on two climate change scenarios, the low and high. These were generated by scaling the magnitude of the outputs of the HADCM2 model to the upper and lower limits of the IPCC ensemble of GCMs (Hulme & Jenkins, 1998). The low and the high scenarios are used as they capture the maximum range of possible responses to the predicted climate change. Two time periods, the 2020s and 2050s, were used as these were the expressed interest of those involved in conservation. The changes in suitable climate space follow the sequence of increasing temperature: 2020s Low, 2050s Low, 2020s High, and 2050s High. The results will focus on the latter, as it is the most severe UKCIP98 scenario, although it probably underestimates the High scenario from the new IPCC outputs (IPCC, 2001).

The output from the trained neural network was a suitability surface scaled from 0 to 1 for each species for each climate change scenario, showing the likelihood of a species being present across Europe and Britain and Ireland. Sensitivity tests were undertaken to determine a threshold value below which the level of suitability is so low that the species was unlikely to be present. This was calculated from the kappa statistic (Appendix 1). The suitability surface was thus converted into a presence/absence map by assuming that all areas with probabilities greater than the threshold value contain

presences. This simulated distribution can then be compared to the recorded distribution using the Atlas of the British Flora (Perring & Walters, 1982). The simulated distribution is often broader than the actual distribution as a number of factors other than climate, such as land cover, competition and history of the species, can act to constrain it.

The outputs for the 54 species were examined in order to identify any consistent response patterns, based on the relationship of current to potential future distributions. The outputs were also examined in relation to the habitats the species represented, to determine if there was a consistent response pattern that could be used to draw conclusions about the potential habitat impact of climate change.

RESULTS

Appendix 1 lists the 54 species modelled along with their habitat association. Full modelling results for each species can be found in the final REGIS (Berry *et al.*, 2001a) and MONARCH (Berry *et al.*, 2001b; http://www.ukcip.org.uk/model_nat_res/model_nat_res.html) project reports. The results are discussed here with reference to individual species and then habitats.

Species

Modelling results show that the responses of individual species to climate change fall into three groups:

Species losing suitable climate space

This group could be subdivided into two subgroups. The first subgroup included species such as trailing azalea (*Loiseleuria procumbens* (L.) Desv.), flat sedge (*Blysmus rufus* (Huds.) Link) and large heath butterfly (*Coenonympha tullia* Müller), which are at the southern limits of their distribution in Britain and Ireland (Fig. 1a). For many of these northern species the simulated current distribution range margin was further south than the actual range margin and this suggests that factors other than climate are constraining their distribution; the most likely being competition (Woodward, 1987) and habitat destruction. Under the climate change scenarios, therefore, the realized distribution may be considerably less than that suggested by the available climate space. In most cases, suitable climate space was progressively lost from the lower parts of Wales, Cumbria, the Pennines and the Southern Uplands, in that order (Fig. 2). Some species, however, such as common storksbill (*Erodium cicutarium* (L.) L'Hérit.) and variegated horsetail (*Equisetum variegatum* Schleich.), lost suitable climate space primarily from north-east England and eastern Scotland. This could be a function of increased dryness in these regions under the climate change scenarios.

The second subgroup was composed of species such as hare's tail cotton grass (*Eriophorum vaginatum* L.), marsh valerian (*Valeriana dioica* L.) and common saltmarsh grass (*Puccinellia maritima* (Huds.) Parl.) which, under the 2020s

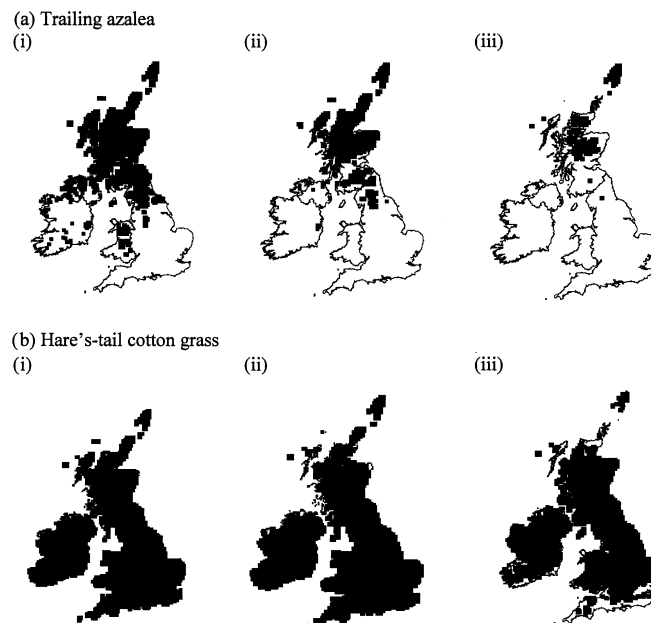


Fig. 1 Species losing suitable climate space, either because they are at the southern limit of their distribution in Britain and Ireland (trailing azalea) or selectively losing suitable climate space in southern England (hare's tail cotton grass): (i) current simulated distribution; (ii) simulated distribution 2050s Low scenario; and (iii) simulated distribution 2050s High scenario.



Fig. 2 Map of Britain and Ireland showing the location of areas referred to in the text.

and 2050s High climate change scenarios, lose suitable climate space in southern England and/or East Anglia (Fig. 1b). They are all representative of wet or moist habitats and the loss is likely to be a response to the greater water deficits projected to occur in summer in these regions (see Dawson *et al.*, 2001).

Species that show little change in their potential future climate space

This group also could be divided into two subgroups. The first subgroup contained species such as cross-leaved heath (*Erica tetralix* L.), cleavers (*Galium aparine* L.) and sweet vernal grass (*Anthoxanthum odouratum* L.), which are found almost throughout Britain and Ireland. This current distribution is well within their European range margins and thus their future distributions do not appear to be directly affected by the projected climate changes (Fig. 3a). The second subgroup was composed of species such as yellow-wort (*Blackstonia perfoliata* L. (Huds.)), great crested newt (*Triturus cristatus* Laurenti) and yew (*Taxus baccata* L.),

which have an unchanging northern range margin in Britain and Ireland (Fig. 3b). This suggests that the magnitude of climate change in the scenarios used is insufficient to generate a shift in range, or that these species' responses are poorly represented by the variables used in the model.

Species expanding their potential future climate space

Other species that have a northern range margin in Britain and Ireland, such as great burnet (*Sanguisorba officinalis* L.), sea purslane (*Atriplex portulacoides* L.) and large skipper butterfly (*Ochlodes venata* Turati), are projected to expand northwards in distribution (Fig. 4a,b). Many of these species are currently altitudinally limited and so under future scenarios could expand into higher elevations. As most of the new northern range margins are in Scotland, this country experiences a considerable influx of species. Also, as the suitable climate space for the first group (i) of northern species contracts, this latter southern group could expand their distributions to fill 'vacant' space, subject to the autecology of the species and any necessary migration.

Habitats

In order to assess the potential impact of climate change on habitats the model results can also be examined according to the habitat association of the species. The species represented 15 habitats, ranging from beech woodland, which is found in southern England, to montane/arctic Alpine habitats located in the higher parts of Britain and Ireland. The varying response of species makes it difficult to assess the impact of climate change on the habitats they represent, but some general conclusions can be drawn.

Arctic–Alpine/montane heath communities showed the greatest sensitivity to climate change. All the modelled Arctic–Alpine/montane heath species were projected to lose suitable climate space, although the loss is very small for some of them under both the Low scenarios. Only one species, the mountain ringlet butterfly (*Erebia epiphron* Knoch.), loses all suitable climate space, but Norwegian mugwort (*Artemisia norvegica* Fr.) is reduced to one suitable grid square by the 2050s High scenario. These observations support the conclusions of the UK Biodiversity Review (Hossell *et al.*, 2000) that the montane category is one of four habitat types particularly sensitive to climate change.

Pine woodland species also showed considerable range loss in the simulations. Both red squirrel (*Sciurus vulgaris* L.) and twinflower (*Linnaea borealis* L.), the two species modelled for pine woodland, lost suitable climate space. The third habitat that could be classified as sensitive was beech woodland. The defining species, beech (*Fagus sylvatica* L.) could lose suitable climate space from a large part of its current distribution in southern Britain (Berry *et al.*, 2002).

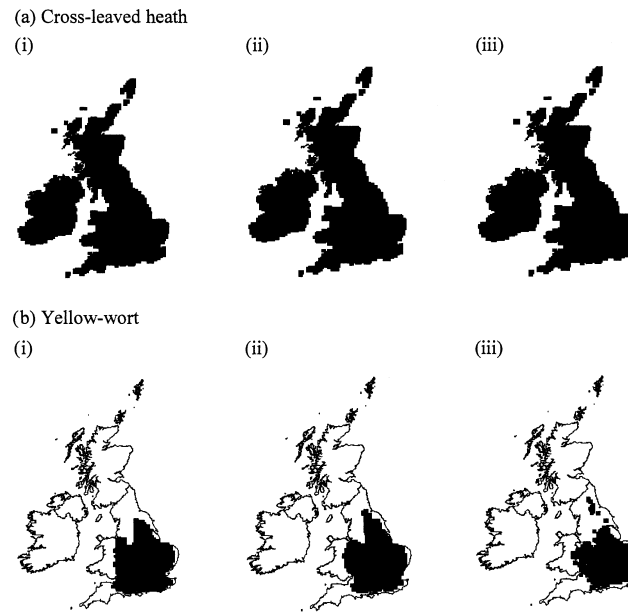


Fig. 3 Species showing little change in their potential future climate space either because the species is found almost throughout Britain and Ireland (cross-leaved heath) or because its northern range margins in Britain and Ireland do not change (yellow-wort): (i) current simulated distribution; (ii) simulated distribution 2050s Low scenario; and (iii) simulated distribution 2050s High scenario.

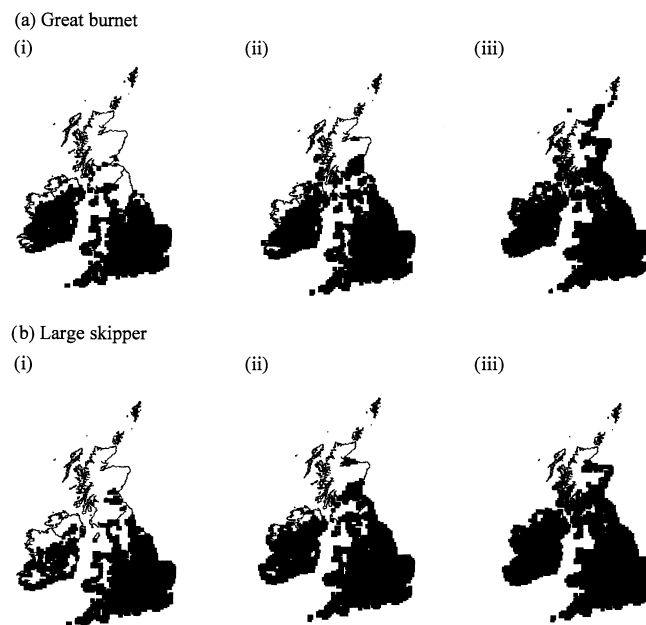


Fig. 4 Species expanding their potential future climate space in response to favourable climatic conditions (great burnet and large skipper): (i) Simulated distribution; (ii) simulated distribution 2050s Low scenario; and (iii) simulated distribution 2050s High scenario.

This loss, however, could be compensated by the addition of large areas of newly suitable habitat in central and northern England and parts of southern Scotland.

In six habitats: lowland heath, wet heath, cereal field margins, coastal grazing marsh, drought-prone acid grassland and calcareous grassland, the species either showed little change or an increase in suitable climate space. These data suggest that, on the basis of the species selected, these habitats are relatively resilient to the direct impacts of climate change. However, in many cases these habitats are especially affected by land use decisions and management practices and these factors may be important in affecting their future species abundance and ranges (Berry *et al.*, 2001a).

Eight of the habitats, however, showed a mixed response. In the upland hay meadows, the two dominant species modelled, sweet vernal grass (*Anthoxanthum odoratum* L.) and crested dog's tail (*Cynosurus cristatus* L.), would not lose suitable climate space. A characteristic species of this habitat, wood cranesbill (*Geranium sylvaticum* L.), along with globe flower (*Trollius europaeus* L.), could experience a loss, while great burnet (*Sanguisorba officinalis* L.) could expand. Similarly, blanket and raised bogs show no clear pattern of response, with two important component species, hare's tail cotton grass (*Eriophorum vaginatum* L.) and bog myrtle (*Myrica gale* L.) remaining widespread, while other species gain or lose suitable climate space. The other habitats showing a mixed response are salt marshes, coastal dune slacks, upland oak woodland and fens. Of these, the fens showed a different mixed response, in that while new suitable climate space is found in Scotland, areas of East Anglia and southern England become unsuitable.

DISCUSSION

The validity of the use of bioclimate envelopes has been questioned (e.g. Woodward & Beerling, 1997; Lawton, 2000), because they assume that climate is the determining factor on a species' distribution and they appear to imply that under the future scenarios an equilibrium with climate will be reached very rapidly. These criticisms are to be addressed elsewhere (work in progress). Here we limit ourselves to the following observations concerning the present use of envelopes. First, it is important to remember that the maps show only areas of potentially suitable climate space and not actual future distributions when down-scaled to Britain and Ireland, as other factors (land use, habitat availability and host plants) may have a more immediate impact on local colonization and survival. Secondly, the migration distance involved in fulfilling the climate space may be beyond the capabilities of some species. However, in favour of the correlative approach is the important advantage that it enables a relatively large selection of species, representative of a wide variety of habitats, to be modelled without the requirement for detailed ecophysiological

data for individual species. Finally, the SPECIES model is applied at the continental scale where climate is expected to be the dominant factor affecting distribution. The ability of the model to train on the basis of climate alone is reflected in the high measure of agreement in many cases between the actual and simulated distributions.

The results for the 54 species are consistent with evidence of the individualistic response of species to climate change (e.g. Huntley, 1991; Huntley *et al.*, 1995; Cannon, 1998; Bale *et al.*, 2002). The large sample of species modelled here means that some generalizations can be made regarding future distributions. Species with a northern range limit in Britain and Ireland may experience an increase in potentially suitable climate space, while those with a southern range margin may experience a loss. Other species are expected to show little change. These species tend to be those for which Britain and Ireland is climatically within their European range margins and thus the shifts in suitable climate space do not fall outside their current distribution. In conjunction with plant functional types (Woodward & Cramer, 1996), climate envelope models could be used to assess which species might gain or lose habitat area at a national level due to climate change. These results also provide a preliminary guide for those responsible for formulating and implementing Species Action Plans by indicating species (and habitats) that are sensitive to climate change.

The details of the species' responses to climate change often varied, because although climate may be the prime factor influencing distribution at the broad scale, other factors which were not included in the model, such as habitat availability, local extinctions and colonization dynamics (Holt & Keitt, 2000) and adaptability (Thomas *et al.*, 2001), may be locally more important. The available suitable climate space may therefore perhaps best be regarded as representing a maximum potential future distribution, that is unlikely to be fully realized due to the operation of these more local factors and, more importantly, the need for species to disperse in order to fulfil parts of these new potential ranges. Several dispersal models are now available (Carey, 1996; Collingham *et al.*, 1996) and these provide information on the possibility of the predicted climate envelopes being filled by the species. If conservation in a particular region is of interest, then it is important to model species at as fine a scale as possible, so that some of these more local factors can be considered.

The existence of suitable climate space, therefore, does not guarantee the future of a species. For example, in the case of natterjack toad (*Bufo calamita* Laurenti) there is no continuous overlap between its current distribution and the modelled potential future climate space. This would further support its status as a UK BAP priority species. There are also species for which the existence of suitable climate space is sufficiently reduced to cause concern and thus further support their

conservation status. This category would include mountain ringlet (*Erebia epiphron* Knoch.), a UK BAP species of conservation concern, which could become extinct under the 2050s High scenario, and Norwegian mugwort (*Artemisia norvegica* Fr.), a UK BAP Priority species, which is reduced to one suitable grid square under this scenario. Although both of these species are found elsewhere in Europe it is thought that the populations in Britain and Ireland represent distinct genetic varieties of the species and thus management for their survival may be considered by some, at least, to be part of maintaining global biodiversity. The SPECIES results also show that with this retreat of northern species, Scotland and upland areas will become increasingly important for British conservation.

The interpretation of the impacts of climate change on habitats is more speculative as it rests on two assumptions. The first is that the species chosen accurately reflect the total habitat response. In many cases, dominants or species used as part of a habitat's classification were modelled and, in these instances at least, this assumption has validity. Beech woodland in southern England, for example, is likely to be under serious threat (Berry *et al.*, 2002). The second assumption is that habitats in the future can be characterized by and will be composed of similar species. Given the individualistic response of species, habitats must be viewed as being composed of temporary assemblages of coexisting species (Huntley, 1991). Wood cranesbill (*G. sylvaticum*), for example, is a diagnostic species of MG3 *Anthoxanthum odoratum*–*Geranium sylvaticum* grassland (Rodwell *et al.*, 1992), which is found in northern England in Cumbria and the Yorkshire Dales, but under the 2050s High scenario these two species will no longer occur together here. Blanket and raised bogs in Cumbria and the Pennines may also see a change in their species composition, although many of the defining species, such as hare's tail cotton grass and bog myrtle, could be unaffected. Thought therefore needs to be given to how habitats are to be classified in the future and how these changes are going to be incorporated into Habitat Action Plans. Further modelling of species for each habitat could increase confidence in the results, but most probably will lead to greater variability in the species' responses, as they continue to display their individuality.

These results therefore represent only a first step in modelling the potential impact of climate change on habitats and species in Britain and Ireland in that they are based on a static model, which does not incorporate the more local and dynamic factors affecting distributions. The limitations that occur are well outlined in Guisan & Zimmerman (2000) and they are starting to be addressed in the second phase of the MONARCH project. Despite these limitations, some preliminary consequences for nature conservation can be identified, indicating what actions may be required at both the management and policy level if the future of some species is to be safeguarded or enhanced.

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BIOSKETCHES

The authors are all members of the Terrestrial Ecology and Biodiversity group in the Environmental Change Institute, University of Oxford.

Dr Pam Berry is an ecologist interested in the impacts of climate change on communities and species, and the implications of climate change for conservation and biodiversity policy.

Dr Terence Dawson is the Programme Leader of the group. His research interests include the application of remote sensing and ecosystem modelling to climate change and vegetation.

Dr Paula Harrison's research interests include the development and application of impact models for agriculture and natural ecosystems, and the evaluation of spatialization techniques for assessing the regional implications of climate change.

Richard Pearson developed the SPECIES model and is working on a cellular automata approach to species' migration responses.

APPENDIX I

Species modelled

Species	English name	Habitat association	Kappa
<i>Alchemilla alpina</i> L.	Alpine lady's mantle	Montane/Arctic alpine	0.64
<i>Andromeda polifolia</i> L.	Bog rosemary	Blanket/raised bog	0.91
<i>Anthoxanthum odoratum</i> L.	Sweet vernal grass	Upland hay meadow	0.90
<i>Artemisia norvegica</i> Fr.	Norwegian mugwort	No association	*
<i>Atriplex portulacoides</i> L.	Sea purslane	Saltmarsh	0.52
<i>Blackstonia perfoliata</i> (L.) Huds.	Yellow-wort	Lowland calcareous grassland	0.72
<i>Blechnum spicant</i> (L.) Roth	Hard fern	Upland oak woodland	0.75
<i>Blysmus rufus</i> (Huds.) Link	Flat sedge	Saltmarsh	0.63
<i>Bufo calamita</i> Laurenti	Natterjack toad	Coastal dune slacks	0.71
<i>Carex bigelowii</i> Torr.	Stiff sedge	Montane/Arctic alpine	0.77
<i>Cirsium acaulon</i> (L.) Scop.	Stemless thistle	Lowland calcareous grassland	0.55
<i>Coenagrion puella</i> L.	Azure damselfly	No association	0.77
<i>Coenonympha tullia</i> Müller	Large heath	Blanket/raised bog	0.90
<i>Cynosurus cristatus</i> L.	Crested dog's tail	Upland hay meadow	0.87
<i>Dryopteris aemula</i> (Ait.) Kuntze	Hay-scented buckler fern	Upland oak woodland	0.75
<i>Epipactis palustris</i> (L.) Crantz	Marsh helleborine	Coastal dune slacks/fens	0.84
<i>Equisetum variegatum</i> Schleich.	Variegated horsetail	Coastal dune slacks	0.57
<i>Erebia epiphron</i> Knoch	Mountain ringlet	Montane/Arctic alpine	0.36
<i>Erica tetralix</i> L.	Cross-leaved heath	Lowland/wet heathland	0.92
<i>Eriophorum vaginatum</i> L.	Hare's tail cotton grass	Blanket/raised bog	0.87
<i>Erodium cicutarium</i> (L.) L'Hérit.	Common storksbill	Drought prone acid grassland	0.75
<i>Fagus sylvatica</i> L.	Beech	Beech woodland	0.81
<i>Galium aparine</i> L.	Cleavers	Cereal field margins	0.96
<i>Gentiana pneumonanthe</i> L.	Marsh gentian	Wet heath	0.88
<i>Geranium sylvaticum</i> L.	Wood cranesbill	Upland hay meadow	0.86
<i>Glyceria maxima</i> (Hartm.)	Sweet reed grass	Fens	0.85
<i>Helianthemum nummularium</i> (L.) Miller	Common rock rose	Lowland calcareous grassland	0.74
<i>Linnaea borealis</i> L.	Twinflower	Pine woodland	0.88
<i>Loiseleuria procumbens</i> (L.) Desv.	Trailing azalea	Montane/Arctic alpine	0.79
<i>Myrica gale</i> L.	Bog myrtle	Blanket/raised bog	0.70
<i>Ochlodes venata</i> Turati	Large skipper	No association	0.85
<i>Orthilia secunda</i> (L.) House	Toothed wintergreen	Upland oak woodland	0.91
<i>Papaver rhoeas</i> L.	Field poppy	Cereal field margins	0.75
<i>Plebejus argus</i> L.	Silver-studded blue	Lowland heathland	0.60
<i>Potamogeton filiformis</i> Pers.	Slender-leaved pondweed	Wetland	0.57
<i>Puccinellia maritima</i> (Huds.) Parl.	Common saltmarsh grass	Saltmarsh	0.73
<i>Ranunculus baudotii</i> Godr.	Brackish water crowfoot	Coastal grazing marsh	0.45
<i>Ranunculus sardous</i> Crantz	Hairy buttercup	Coastal grazing marsh	0.72
<i>Ranunculus scleratus</i> L.	Celery-leaved buttercup	Fens	0.67
<i>Rhynchospora alba</i> (L.) Vahl.	White-beaked sedge	Blanket/raised bog	0.83
<i>Rubus chamaemorus</i> L.	Cloudberry	Blanket/raised bog/ Montane/Arctic alpine	0.90
<i>Salix herbacea</i> L.	Dwarf willow	Montane/Arctic alpine	0.70
<i>Sanguisorba officinalis</i> L.	Great burnet	Upland hay meadow	0.85
<i>Sanicula europaea</i> L.	Sanicle	Beech woodland	0.85
<i>Scandix pecten-veneris</i> L.	Shepherd's needle	Cereal field margins	0.78
<i>Sciurus vulgaris</i> L.	Red squirrel	Pine woodland	0.89
<i>Silene otites</i> (L.) Wibel	Spanish catchfly	Drought prone acid grassland/ cereal field margin	0.88

APPENDIX I *continued.*

Species	English name	Habitat association	Kappa
<i>Sphagnum papillosum</i> Lindb.	Sphagnum bog moss	Blanket/raised bog	0.73
<i>Suaeda maritima</i> (L.) Dumort.	Annual seablite	Saltmarsh	0.63
<i>Taxus baccata</i> L.	Yew	Beech woodland	0.53
<i>Trifolium fragiferum</i> L.	Strawberry clover	Coastal grazing marsh	0.89
<i>Triturus cristatus</i> Laurenti	Great crested newt	No association	0.62
<i>Trollius europaeus</i> L.	Globe flower	Upland hay meadow	0.66
<i>Valeriana dioica</i> L.	Marsh valerian	Fens	0.82

* No kappa cut-off was used due to the difficulty of training on only 12 points in the European distribution.