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The potential for spread of alien species in England following climatic change

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The potential for spread of alien species in England following climatic change

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SUMMARY

Enhanced greenhouse warming will result in northward spread of native and alien plant species. The main purpose of the review is to assess the consequent threat posed by spread of alien and potentially invasive species to biotopes of nature conservation interest in England.

Compared with 1975, in 2050 the English climate is predicted to be about 1.0°C warmer in summer and 2.0°C warmer in winter, with a 5% increase in rainfall. For 2100 the predicted difference is 2.5°C in summer and 3.0°C in winter, with a 10% increase in rainfall.

A measure of climate similarity across Europe was defined using species occurrence data from *Atlas Florae Europaeae*, combined with European climate normals for 0.5° cells. This measure of similarity can be used to cluster English Nature regions. Ten clusters were derived. The similarity of their present and future climate to that of other parts of Britain and Europe was compared.

In 2050, climates of northern England will resemble current climates of Wales and southern England; by 2100 they will be more similar to that currently experienced in Brittany. In 2050, climates of southern England will resemble the present climate of Brittany; by 2100 they will be more similar to those of southwest France and northern Spain.

Lists of aliens likely to increase were assembled from several sources including the checklist of Kent (1992) and the database of the BSBI Monitoring Scheme. Species with a southern tendency were selected on the basis of their occurrence in countries listed in *Flora Europaea*. This gave a useful preliminary indication, but was relatively unreliable for species not native to Europe.

A fuller analysis was based on (a) the 204 most frequently recorded aliens in the BSBI Monitoring Scheme and (b) 228 species selected subjectively from Stace's (1991) flora. From these sources, two shortlists were made. The first shortlist, of 50 species, was of plants with a southerly tendency that are already frequent and threatening biotopes of nature conservation interest. The second shortlist, of 73 species, included any plants thought likely to show a marked increase, regardless of biotope, provided that they were not on the first shortlist.

The great majority of species in both shortlists were of species that are commonly cultivated in gardens. The only other important category was that of weeds of gardens and waste places. Because of the ubiquity of gardens in England, very few of these aliens are likely to have major dispersal difficulties.

The threat to woods, grasslands and heaths is small. There is very little evidence that climate warming will facilitate invasion of new species, although cherrylaurel *Prunus laurocerasus* may increase in some woodlands. Grassland is particularly unlikely to be invaded. The main threat to grassland and heaths comes from tree and shrub invasion, but this

is a current threat and should not be increased by climate warming.

Cliffs, dunes and strandlines, on the other hand, are not only strongly invasible but have a relatively large suite of species that may colonize them. These present a threat only where the new arrival is likely to form dense thickets, thereby excluding indigenous plants by smothering. Suckering shrubs on dunes and dense shrubs such as *Cotoneaster* species on inland and coastal rocks are examples of such threats.

Much the most serious current and future threat to coastal habitats is Hottentot fig *Carpobrotus edulis*. This forms dense mats, is spread by many agencies including gulls, and is almost impossible to eradicate. It may be capable of control by grazing, but that is not an option on many cliffs. Perhaps the only viable control method is a combination of vigilance and early eradication.

1 INTRODUCTION

1.1 ORIGIN OF THE CONTRACT

In August 1993, the Institute of Terrestrial Ecology applied successfully for a research contract with English Nature to predict the potential for spread of alien plants in England following climate change. Work began in September 1993.

1.2 BACKGROUND AND THE POTENTIAL OF ALIEN SPECIES

Accidental and deliberate movements of animals, plants and their propagules have markedly increased the rate of arrival of new species to Britain over the past two centuries. For some groups the rate of arrival is perhaps now at an all-time high. However, vigorous quarantine restrictions, increased seed-cleaning, and changes in industrial practices have reduced the rate of arrival of certain species such as agricultural pests, cornfield weeds and Australian aliens formerly imported in wool. A list of introduced plant species, together with putative means by which they reached Britain, is given by Crawley (1987). For a more general review, emphasizing animals, of introduced species in Britain refer to Eversham & Arnold (1992).

The great majority of introduced aliens do not establish persistent populations but die out after one or a few generations because they are not suited to local conditions. With plants, two of the commonest causes of failure are an inability to survive the local climate and competition from the native flora. Darwin (1859) pointed out that many plants can survive in gardens when they are quite unable to persist in the wild. However, as many gardeners know to their cost, keeping alpines alive through the moist British winter and keeping frost-tender species alive through cold spells can be quite a challenge.

1.3 IMPACTS OF INTRODUCED SPECIES

On remote oceanic islands the damage done by introduced species to natural ecosystems is often catastrophic. Britain, although now an island, was connected by a land bridge to Europe until about 5500 B.C. and therefore has a biota that is essentially continental in character (Pennington, 1969). The damage done by introduced species has accordingly been less severe. Interestingly enough, two of the most invasive woody species, rhododendron (*Rhododendron ponticum*) and sycamore (*Acer pseudoplatanus*), are both indigenous to Europe. They failed to reach this country because of unsuitable terrain between Britain and their native range.

Whereas animals are thought quite frequently to exclude one another, the case for competitive exclusion in plants is poor. Indeed, Crawley (1987) argues that there is no evidence that any plant species has been excluded from any plant community in Britain by competition with aliens. He attributes this to the short time that these aliens have been present.

There is, however, no cause for complacency. Large tracts of land have already been modified by invaders such as sycamore and rhododendron. These species reduce the integrity of our cultural and semi-natural landscape and are likely to reduce local biodiversity. They are academically interesting but contribute to a loss of our heritage.

1.4 EFFECTS OF CLIMATE CHANGE

The climate is expected to warm by about 2.0°C by the year 2050, with winters warmer by 2.0°C and summers warmer by 1.0°C (see below, Section 2.1). In response to the predicted warming, species ranges can be expected to shift northwards by a few hundred kilometres. In this way, aliens that are currently rare and restricted to the south may become common; others that are only sporadic may become established; and some that are currently unknown in Britain invade.

Such northward movements of alien plants present a distinct threat to existing British biotopes, including many that are of nature conservation interest. However, the magnitude of this threat is not known; nor is it known whether the threat can be reduced by taking corrective action to prevent invasion.

1.5 OBJECTIVES

The study is restricted to vascular plants and concentrates on their potential future occurrence in England. The following main objectives can be identified:-

1. To review the threat posed by the spread or establishment of alien and potentially invasive species to biotopes of nature conservation interest in England.

2. To indicate the type of control measures applicable to species presenting the greatest such threat.

1.6 STRUCTURE OF REPORT

A substantial chapter is devoted to a climate change scenario for England. This is interpreted in terms of analogue climates in nearby parts of Europe.

The availability of invasive species is then assessed, drawing on a variety of sources, notably the checklist of Kent (1992), the flora of Stace (1991), a computerized list of species in *Flora Europaea* (Tutin *et al.* 1964-1980), the BSBI Monitoring Scheme (Rich & Woodruff, 1990) and floras of the Channel Islands and Isles of Scilly. Many of the resulting lists of species and their attributes are too long to include in the main part of the report and are presented as appendices.

A short chapter is devoted to the flora of those parts of Europe that were identified as having present climates analogous to those that will prevail in England in future.

Drawing on this source of information, the threat to habitats is assessed, comparing habitats that are threatened at the present time with those that are likely to be occupied by southern aliens.

A short chapter is devoted to dispersal.

Finally the threat posed by aliens to semi-natural habitats is assessed, and possible control measures are set out.

2 CLIMATE OF ENGLAND IN THE YEARS 2050 AND 2100

2.1 PREDICTED CHANGES IN CLIMATE

It has been recognized that as a result of human activities the concentrations of greenhouse gases are increasing, and ultimately these are producing an additional warming of the Earth's surface (Houghton, Jenkins & Ephraums, 1990). Predictions of future climates are steadily improving, and are summarized as scenarios, derived from results of general circulation models (GCMs). For the present study, we used the IS92a scenario (Houghton, Callander & Varney 1992), which represents an update on the IPCC 1990 'Business-as-Usual' scenario. This scenario, global in scope, was interpreted at the scale of Great Britain by Climatic Research Unit (CRU) using the ESCAPE model. For the year 2050, Summer (June, July, August) mean temperature is predicted to rise by 1.0°C across England, Winter (December, January, February) mean temperature will rise between 1.5-2.0°C, and annual precipitation is expected to rise by 5.0%. For the year 2100, Summer mean temperature is expected to rise by between 2.5-3.0°C, winter temperature by between 3.0-3.5 °C, and annual precipitation is predicted to increase by between 10.0-15.0%.

2.2 A MEASURE OF FLORISTIC SIMILARITY FOR EUROPEAN CLIMATES

Previous studies (e.g. Jones & Bunce 1985) have classified and ordinated the European climate on the basis of climatological variables, without regard for the effects of climate on species. There is a logical problem here, in that only climate variables are considered, and not their effects; the result depends strongly on the choice of variables. For example, it has to be assumed that differences in rainfall across Europe produce a roughly similar effect to differences in temperature.

A way of overcoming this difficulty is to ordinate the physical environment by detrended canonical correspondence analysis (Ter Braak 1986), using data on the presence and absence of species in various geographical regions. In this way, a metric of similarity in environmental space is derived, reflecting species similarity. This approach has been used by Hill (1991) and also by Carey *et al.* (1994) in an unpublished report to Scottish Natural Heritage.

The measure of climatic similarity can be used to find analogues for the English climate in future. Taking predicted climate changes from the scenario, the distance between a given future climate and existing European climates can be measured. Thus it is possible to map those areas whose present climate resembles future English climates.

2.3 BASELINE CLIMATE DATA

Baseline European climate data for the period 1961-1990 were provided by CRU. This baseline dataset was interpolated from observed station data distributed throughout Europe and North Africa, generating climatologies at a spatial resolution of 0.5° (representing

12499 cells within the European window). This dataset is held in ARC/INFO and the following five variables were used in this analysis:-

1. Minimum January temperature at lowest altitude in cell
2. Minimum January temperature at highest altitude in cell
3. Maximum July temperature at lowest altitude in cell
4. Maximum July temperature at highest altitude in cell
5. Annual precipitation total at mean altitude in cell.

2.4 SPECIES DATA

Species distribution data for Europe were available in the form of digitized distribution maps from *Atlas Florae Europaeae* (AFE) (Jalas & Suominen 1972-1989). These data were supplied by the Environmental Research Centre in digital format; a few species distributions were digitized at Monks Wood from other sources. Thirty species were chosen (Table 2.1), and since these are held at the 50km resolution of the AFE grid, they were resampled using ARC/INFO GIS to the same 0.5° resolution as the climate data. One additional 'species' was added to the thirty species distributions, and this was given a weight of 0.001 in each of the 12499 cells that covered the European window, maintaining a notional species presence in every cell. The purpose of this 'species' was purely to save computation, by ensuring that no cell was apparently lacking in species complement (cells with no species would be ignored by CANOCO).

Table 2.1. European species analysed by CANOCO, in order to derive a measure of climatic difference between 0.5° cells.

Abies sibirica	Ophrys apifera
Agrostis curtisii	Pinus halepensis
Alnus incana	Pinus mugo
Betula nana	Pinus sibirica
Carpinus betulus	Populus alba
Catanea sativa	Pulsatilla vulgaris
Celtis australis	Quercus cerris
Himantoglossum hircinium	Quercus petraea
Humulus lupus	Quercus suber
Juniperus phoenicea	Salix lanata
Juniperus sabina	Salix reticulata
Larix decidua	Selaginella selaginoides
Larix sibirica	Taxus baccata
Loranthus europaeus	Ulmus glabra
Myrica gale	Viscum album

2.5 DETRENDED CANONICAL CORRESPONDENCE ANALYSIS (DCCA)

The two sets of data were then analyzed by DCCA with detrending by segments, using he computer program CANOCO (Ter Braak, 1988). This method uses the species data to 'train' the environmental data in a similar way to that used in multiple discriminant analysis (also known as canonical variate analysis; Digby & Kempton 1987). The four-axis environmental ordination produced by CANOCO was used for further analysis.

The four-axis environmental dataset was then imported into ARC/INFO and then displayed in such a way as to highlight the floristically similar zones for the European climate by showing them as bands of similarity along each of the environmental axis (Figures 2.1 to 2.8).

These derived environmental variables are each a linear combination of the five variables listed above. Equations for each were calculated using the statistical computing package GENSTAT (Table 2.2).

Table 2.2. Equations used to derive DCCA axes from original climate variables. The original variables are: x_1, January mean daily minimum temperature (°C) for lowest altitude in square, x_2 January mean daily minimum temperature (°C) for highest altitude in square, x_3 July mean daily maximum temperature (°C) for lowest altitude in square, x_4 July mean daily maximum temperature (°C) for lowest altitude in square, x_5 annual precipitation (mm) for mean altitude in square.

$$\text{Axis1} = 185.2840 - 27.1994*x_1 + 14.4488*x_2 + 2.1622*x_3 - 14.6154*x_4 + 0.0225452*x_5$$

$$\text{Axis2} = -467.2714 - 6.1233*x_1 - 0.4840*x_2 + 11.8804*x_3 + 5.5007*x_4 + 0.0460587*x_5$$

$$\text{Axis3} = -15.8467 + 13.7755*x_1 - 15.0524*x_2 - 2.8355*x_3 + 2.1577*x_4 - 0.0211372*x_5$$

$$\text{Axis4} = -101.5622 - 8.0341*x_1 + 7.1828*x_2 + 5.0546*x_3 - 3.0139*x_4 + 0.0741924*x_5$$

2.6 CLUSTERING OF ENGLISH NATURE NATURAL AREAS

British baseline climate data for the period 1961-1990 were also generated by CRU on a 10-km raster. The five variables used in the analysis of the European climate were attached to each of the seventy-six English Nature Natural Areas using the GIS. A mean climate for each Natural Area was then calculated, taking an average over all 10-km squares which were at least parly in the Natural Area. The means were then converted to the derived environmental space consisting of the four ordination axes specified in Table 2.2.

To obtain a manageable number of sites for the analogue climate study, a computer program written by Moss (1985) which employs a k-means (minimum variance) clustering algorithm was used to group the Natural Areas in ten clusters. These clusters are detailed in Table 2.3, and shown in Figure 9.

The mean baseline climate for each of the clusters is shown in Table 2.4, and this is compared with that of other, comparable, regions of atlantic Europe.

2.7 ANALOGUE CLIMATES FOR ENGLAND IN 2050 AND 2100

Using the centroids generated in the k-means clustering algorithm it was then possible to identify analogous regions to each of the 10 clustered Natural Areas. This was performed by calculating Euclidean distances in the four dimensional environmental space between each of the clusters and each one of 12499 cells within the European climate window. This was performed initially to identify regions within Europe which are analogous to each of the ten Natural Area clusters with the present climate.

To derive future analogue climates, this procedure was repeated, altering the mean climate for each Natural Area to that appropriate to the years 2050 and 2100 (see section 2.1) to identify current analogous regions within Europe. The climate changes were applied to each cluster centroid as detailed in Tables 2.5-2.8. The position of each cluster in the derived environmental space was recalculated, and similarities based upon Euclidean distances determined.

The results are shown in Figures 2.10-2.19. For example in Figure 2.10, the Natural Area cluster 1 (representing the Lake District and Yorkshire Dales) has current strong analogous climates in the Scottish Southern Uplands and coastal Norway; under the climate change scenario for 2050, there are some similar regions in western England and Wales; and for the year 2100 there is only a slight resemblance to South Wales. Similarly for cluster 10, the Lizard, current strong analogous climates exist in southwest England and the Channel Islands; for the year 2050, close similarities exist in northwestern France (Brittany); and for the year 2100, slight similarities exist to the present climate of coastal northern Spain.

2.8 BRITAIN AND ITS POSITION IN ENVIRONMENTAL SPACE

A clearer impression of the meaning of environmental space and of the method by which similarities have been derived is given in Figures 2.20 and 2.21. In Figure 2.20, the position of Britain is shown in environmental space. In the two dimensions shown, its climate overlaps slightly with Norway and the Channel Islands. Brittany is slightly different, and northern Spain more markedly so.

The changes predicted by the scenario are represented by a scatter diagram in environmental space (Figure 2.21). The movements of the clusters are from right to left. Clusters 8 and 9 move in the direction of Brittany and northern Spain. But cluster 10 (the Lizard) moves out into a region that lacks a current European analogue. Perhaps its future climate would resemble that of an island in middle of the Bay of Biscay; but no such island exists.

2.9 SPECIES DISTRIBUTIONS IN ENVIRONMENTAL SPACE

In order show how species are distributed in environmental as well are real space, a series of five scatterplots (Figures 2.22-2.26) is given for selected species. These were chosen as ones for which distributional data were available, not as British aliens. The British Isles are on the edge of the range of *Quercus ilex*, but, interestingly, are not on the edge of that of *Q. cerris*. Nevertheless, *Q. cerris*, a species of more continental climates, has naturalized quite well here.

Table 2.3. Clusters of English Nature Natural Areas. Areas in the clusters have a similar climate and altitudinal range.

<u>Cluster 1: Northwest uplands</u>

8 Lake District
11 Yorkshire Dales

<u>Cluster 2: Northern</u>

1 Border Uplands
2 Northern Pennines
6 Solway Basin
7 Eden Vale
9 Cumbrian Coastal Plain
10 Morecombe Bay Limestone
12 Southern Pennines
18 The Dark Peak
30 The White Peak

<u>Cluster 3: Northeast</u>

3 Northumberland Coastal
4 Tyne Vale
5 Durham Magnesium Limest
14 North York Moors

<u>Cluster 4: North central</u>

13 Vale of York
15 Yorkshire Wold
16 Plain of Holderness
17 Lancashire Plain
19 Coal Measures
24 Lincolnshire Wolds
25 Lincolnshire Coastal Pl
29 Lower Derwent Valley
31 Staffordshire Northern
32 Mosses and Meres
33 Shropshire Uplands
34 Upper Trent Valley
73 Black Mountains

<u>Cluster 5: Southwest</u>

60 Exmoor and Quantocks
61 Culm Measures
62 Dartmoor
70 South West Plain
71 Bodmin

<u>Cluster 6: Lowland southern</u>

20 Derbyshire Magnesium Li
21 Sherwood Forest
22 Trent Valley and Levels
23 Cover Sands
26 Lincolnshire Clay Vales
27 Lincolnshire Limestone
37 North Norfolk
40 Broadland
41 Sanderlings
53 North Kent Plain
66 South Downs
69 Romney Marsh

<u>Cluster 7: Midlands</u>

28 Fenland
35 Birmingham Plateau
36 Wark Sandstone Plateau
38 Breckland
39 East Anlian Plains
42 East Midlands Lowlands
43 Greater Cotswolds
44 Severn Valley
46 Hereford Plain
48 Oxford Clay Vales
49 Wessex Downs
50 Chilterns
54 North Downs
56 Hampshire Chalk
75 Beds Greensand
76 Oxford Heights

<u>Cluster 8: Southern</u>

47 Mendips
55 Greensand
57 Salisbury Plain and Dor
58 Vale of Taunton
59 Somerset Levels
63 Devon Sandstone
64 Blackdowns
65 Hampshire Basin
67 Low Weald
68 High Weald
74 Severn/Wye Plateau

<u>Cluster 9: Thames basin</u>

45 Malvern Hills
51 London Basin
52 Thames Marshes

<u>Cluster 10: Lizard</u>

72 The Lizard

Table 2.4. Baseline (1975) climate of clustered Natural Areas compared with other sites in atlantic Europe.

Cluster	Jan T (°C)		Jul T (°C)		Annual precip (mm)
	Low alt	High alt	Low alt	High alt	
1 NW Uplands	0.5	-1.7	18.7	15.4	1573.1
2 Northern	0.6	-0.8	19.0	16.9	1102.5
3 Northeast	0.8	0.1	18.8	17.7	704.8
4 North C	1.0	0.2	20.0	18.9	801.4
5 Southwest	3.3	2.1	19.6	18.0	1239.6
6 Lowland S	1.2	0.8	20.6	20.1	651.6
7 Midlands	0.8	0.3	21.3	20.5	690.3
8 Southern	1.9	1.2	20.8	19.8	842.2
9 Thames	1.5	0.9	21.8	20.9	645.2
10 Lizard	4.8	4.2	19.3	18.5	925.5
Norway	-0.4	-3.3	18.2	15.0	1711.5
Channel Islands	4.7	4.2	19.6	19.1	895.4
Brittany	4.1	3.2	21.8	20.8	980.0
Northern Spain	6.0	5.2	22.5	21.7	835.2

Table 2.5. Predicted changes in climate for clustered Natural Areas in the year 2050.

Cluster	Winter T (°C)	Summer T (°C)	Annual precip (%)
1 NW Uplands	2.0	1.0	5.0
2 Northern	2.0	1.0	5.0
3 Northeast	2.0	1.0	5.0
4 North C	1.5	1.0	5.0
5 Southwest	2.0	1.0	5.0
6 Lowland S	2.0	1.0	5.0
7 Midlands	2.0	1.0	5.0
8 Southern	2.0	1.0	5.0
9 Thames	2.0	1.0	5.0
10 Lizard	1.5	1.0	5.0

Table 2.6. Predicted climates for clustered Natural Areas in the year 2050.

Cluster	Jan T (°C)		Jul T (°C)		Annual precip (mm)
	Low alt	High alt	Low alt	High alt	
Northern Spain	6.0	5.2	22.5	21.7	835.2
1 NW Uplands	2.5	0.3	19.7	16.4	1651.8
2 Northern	2.6	1.2	20.0	18.0	1157.6
3 Northeast	2.8	2.1	19.8	18.7	740.1
4 North C	3.0	2.2	21.0	19.8	841.5
5 Southwest	4.8	3.6	20.6	19.0	1301.6
6 Lowland S	3.2	2.8	21.6	21.1	684.2
7 Midlands	2.8	2.3	22.3	21.5	724.8
8 Southern	3.9	3.2	21.8	20.8	884.3
9 Thames	3.5	2.9	22.8	22.0	677.5
10 Lizard	6.3	5.7	20.3	19.5	971.8

Table 2.7. Predicted changes in climate for clustered Natural Areas in the year 2100.

Cluster		Winter T (°C)	Summer T (°C)	Annual precip (%)
1	NW Uplands	3.5	2.5	15.0
2	Northern	3.5	2.5	15.0
3	Northeast	3.5	2.5	15.0
4	North C	3.5	2.5	15.0
5	Southwest	3.5	2.5	10.0
6	Lowland S	3.5	3.0	15.0
7	Midlands	3.5	3.0	10.0
8	Southern	3.5	3.0	10.0
9	Thames	3.5	3.0	10.0
10	Lizard	3.0	2.5	10.0

Table 2.8. Predicted climates for clustered Natural Areas in the year 2100.

Cluster	Jan T (°C)		Jul T (°C)		Annual precip (mm)
	Low alt	High alt	Low alt	High alt	
1 NW Uplands	4.0	1.8	21.2	17.9	1809.1
2 Northern	4.1	2.7	21.5	19.5	1267.9
3 Northeast	4.3	3.6	21.3	20.2	810.6
4 North C	4.5	3.7	22.5	21.4	921.6
5 Southwest	6.8	5.6	22.1	20.5	1363.6
6 Lowland S	4.6	4.3	23.6	23.1	749.3
7 Midlands	4.4	3.8	24.3	23.5	759.3
8 Southern	5.4	4.7	23.8	22.8	926.4
9 Thames	5.0	4.4	24.8	24.0	709.7
10 Lizard	7.8	7.2	21.8	21.0	1018.0