Forest Research

Priorities for research on emerging species

A summary of an analysis based on species diversity in present and future environments

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Summary

This report summarises the variation in the diversity of forest tree species in different climatic regions of Britain. Progress on three areas is reported:

1. An analysis of species diversity in different climate regions to identify shortfalls.
2. The extent to which species can substitute for each other if one gets into trouble using estimates of species climate space.
3. The identification of novel future climates that may require additional species.

Measured species diversity, which takes account of relative abundance, in the wet climate regions of Britain that are dominated by Sitka spruce is low and is being further reduced in terms of useable species by the impacts of new pests and diseases. However, species richness (the total number of species present) is high in these regions so there appears to be an underlying diversity of currently low abundance species that require research to determine if they could be more widely planted in the future.

In addition, the potential impacts on species composition of shifts in climate zones caused by climate change are examined and gaps identified for future climates. In particular, the appearance of novel warmer climates for Britain requires research to determine impacts on existing species and to continue evaluation of new species and provenances.

The report concludes with a series of recommendations on directions for future research within the Emerging Species Work Area.

1. Introduction

The trees used in British forestry are a mix of native and introduced species. The selection of species for forestry involves two broad considerations: biological suitability and the fulfilment of economic and other objectives (Anderson, 1961). The assemblage of species that are adapted to the climate and soils of an area provide a pool from which appropriate ones can be selected to meet objectives. Sufficient numbers (richness) of species have to be maintained in these pools to meet present and future needs.

Current choices and recommendations about species are based on decades of research and practical experience. However, increasing incidences of new pests and diseases are eroding species richness by partially or completely preventing continued use of important species. Furthermore, projected shifts in regional climates caused by climate change will require alterations to the composition of available species by, for example, increasing the number of species or provenances that can tolerate the warmer drier conditions that are projected to occur more frequently in southern Britain. Consequently, forestry practice is shifting away from reliance on a few familiar principal species to utilisation of a more diverse range of trees (see 2.3 Definitions for descriptions of the main categories of species).

Although the need for species diversification is well understood, research on extending species choice requires a greater understanding of species diversity in the different regional environments of Britain. This helps to identify situations where additional species are required to increase diversity and to ensure compatibility with the future climate. It is important to determine priorities to ensure that resource is focussed on filling deficits in important species groups rather than adding new species to situations where there are already adequate pools of species. This report is a summary of the main findings from an internal technical report that presents the logic, analyses and findings in more detail (Jinks, 2017).

Progress on three areas is summarised:

1. An analysis of species diversity in different climate regions to identify shortfalls.
2. The extent to which species can substitute for each other if one gets into trouble using estimates of species climate space.
3. The identification of novel future climates that may require additional species. This work is in progress and some initial results are presented to illustrate the approach being used.

2. Approach and methods

2.1. Approach

The geographic distribution of species is limited by many factors including tolerances to environmental conditions such as temperature, moisture and light. In theory it's possible to combine all the biotic and physical factors as axes on a multi-dimensional graph to define a hypervolume that encompasses the region where a species can survive, grow and reproduce.

But it is impossible in practice to determine the responses of species to all environmental factors and most investigations on species distribution limit these to the two or three most important ones. Temperature and moisture are key factors that affect the geographic distribution of trees and these can be combined as two axes to describe the two-dimensional climate space that a species occupies. Each species will have its own unique climate space that describes its temperature and moisture limits.

The relationships summarised in this report are intended to capture elements of the autecology of species rather than provide all the information needed for species choice in particular planting situations; Ecological Site Classification, ESC (Pyatt, Ray, & Fletcher, 2001) is designed to incorporate the sophistication needed to meet this requirement at the site-scale.

2.2. Methods

2.2.1. Analysis of species diversity in different climate regions

The measurement of species diversity requires a convenient method for defining non-overlapping groups of the species that are growing across a country or other geographic unit. Groupings can be done using political or geographic boundaries, but division into climatic regions or domains that contain similar ranges and abundances of species are more useful for analysing diversity.

The construction of climate regions was done in three stages:

1. The Forestry Commission subcompartment database (SCDB) was used as a source of location data on species abundance across Britain. Although this data source limits the study to the Public Forest Estate, its extent provides a reasonable coverage of the main forest areas of Britain. In future, analysis could be extended to include suitable data for woods and forest under other ownership. The twenty most abundant species in the SCDB were selected for analysis (Table 1), and local values of temperature and precipitation for each location were extracted from WorldClim gridded climate data files for Britain (Hijmans, Cameron, Parra, Jones, & Jarvis, 2005).

2. The climate variables were converted to an accumulated temperature and modified wetness scale (see 2.3 Definitions) which were used to calculate bioclimates (**climate zones**) that formed the basic categorical units within which species are distributed. The bioclimate classification system of Rivas-Martinez and Rivas-Saenz (1996) was adopted for this study because the classification is based on the correspondence between vegetation and climate and so is biologically relevant. It is a global system that enables direct comparison of present and future climate zones in Britain with regions elsewhere in the world.

3. Statistical clustering algorithms were then applied to climate zone categories for aggregating zones with similar species composition and abundance into non-overlapping **climate regions** that can be considered as equivalent to the main silvicultural regions of Britain.

Table 1. List of species analysed for this report.

Species code	Common name	Latin name
SS	Sitka spruce	*Picea sitchensis*
SP	Scots pine	*Pinus sylvestris*
LP	Lodgepole pine	*Pinus contorta*
CP	Corsican pine	*Pinus nigra* ssp. *laricio*
JL	Japanese larch	*Larix kaempferi*
BI	Silver birch and Downy birch	*Betula pendula* and *B. pubescens*
NS	Norway spruce	*Picea abies*
OK	Sessile oak and Pedunculate oak	*Quercus petraea* and *Q. robur*
DF	Douglas-fir	*Pseudotsuga menziesii*
BE	Beech	*Fagus sylvatica*
HL	Hybrid larch	*Larix × eurolepis*
EL	European larch	*Larix decidua*
AH	Ash	*Fraxinus excelsior*
WH	Western hemlock	*Tsuga heterophylla*
SY	Sycamore	*Acer pseudoplatanus*
SC	Sweet chestnut	*Castanea sativa*
GF	Grand fir	*Abies grandis*
RC	Western red cedar	*Thuja plicata*
NF	Noble fir	*Abies procera*
LC	Lawson cypress	*Chamaecyparis lawsoniana*

2.2.2. Estimating species climate space, defining species climate types, and analysing potential substitution.

Climate space is a basic attribute of a species in relation to the environment and its measurement can be approximated by using the same local values of temperature and moisture extracted from the geographic locations where a species is growing. The analysis of patterns of abundance in climate space results in complex shaped polygons that contain contours showing regions of differing abundance and these are presented and discussed in detail in the technical report. In this summary report, the polygons are simplified by fitting ellipses to the climate regions with high abundance of occurrence to show the core climate space region occupied by species. Note: species are of course present at locations outside their ellipses but are present at lower abundance.

Species climate space was analysed in two ways. Firstly, species with similar climate spaces were grouped into four main **climate types of species**. Secondly, the amount by which the climate spaces of any two species overlap was calculated to measure the extent to which species can **substitute** for each other in particular climate regions. In addition, the extent to which species occur on similar soil groups within the overlap region was assessed using digital records of soil types that were amalgamated into soil groups.

2.2.3. Future changes in climate zones

To assess the extent to which current subcompartments shift climate zones in future climate change scenarios, projected climate data for all subcompartments were obtained for the 2050s derived for four increasing greenhouse gas concentration scenarios (RCP, Representation Concentration Pathway) from the HadGEM2-ES Global Circulation Model (GCM) (Collins et al., 2011). For brevity in this report, climate shifts are summarised for the main temperature zones only and so are averaged across wetness zones.

The possibility of mapping future novel climates to regions of the world that currently have similar climates to these projected climates is demonstrated using WorldClim gridded climate data.

2.3. Definitions

Temperature (T_p) The annual positive temperature of a location, which is the sum of monthly positive temperatures and is used as a measure of climatic warmth.

Wetness (I_o) is the yearly positive precipitation divided by T_p and is a simplified measure of wetness or aridity.

Climate zones are the basic categorical units of climate produced by combining divisions of T_p and I_o. The temperature scale is divided into Warm, Cool and Cold categories, and wetness is divided into Dry, Humid, Very Humid, Wet, Very Wet and Extremely Wet regions. Zones are referred to by the respective abbreviated T_p and I_o levels, e.g. Cool:VWet. For the Very Wet region of the Cool temperature range.

Climate regions are four groups of climate zones that have similar ranges and abundances of species. These are labelled by combining the main temperature and wetness zones covered by the grouping: warm-dry, cool-humid, cool-wet and cold-wet.

Species categories: species can be categorised into four groups according to the extent of current use in forestry and how much is known about their silvicultural characteristics (Kerr & Jinks, 2015)

> **1. Principal tree species** are defined as species that are currently widely used for timber production and will continue to be dominant species unless affected by a new pest or disease or become adversely affected by climate change.
>
> **2. Secondary tree species** are trees that have been planted on a much smaller scale than the principal species because they are restricted to particular climate zones or have been overshadowed by more popular principal species. The qualities of secondary species are reasonably well understood and they have demonstrated their suitability for forestry under current conditions and so have potential for wider use in future.
>
> **3. Plot-stage species** are a group of species that have not been planted commercially on any significant scale, but have demonstrated positive silvicultural characteristics in trial plots and have qualities suitable for forestry objectives to justify further testing and development.
>
> **4. Specimen-stage species** are species that have not been trialled for forest potential in experimental plots, but have demonstrated as specimens in tree collections positive traits of good form, growth rate and hardiness to warrant further testing in plots on a limited scale. Work on identifying these species is currently covered by a separate Arboreta project.

Species climate types are groups of species that occupy similar zones of climate space. Four are defined: warm and cool types are species that predominantly confined to warm and cool temperature zones respectively. Dry-humid and humid-wet types are species that occur in both warm and cool zones, but whose wetness extent is either restricted to drier regions (dry-humid) or extends across all wetness zones into wetter zones (humid-wet).

Species diversity within a region is measured as **species richness**, which is the total number of species and has a maximum value of 20 in this study, and the **Shannon Index** of species diversity, which takes the relative abundances of different species into account and typically ranges between 1.5 and 3.5 in ecological studies. The index is logarithmic and can be interpreted by back-transformation as the effective number of equally abundant species thus an index of 1 is equivalent to 2.7 evenly distributed species, 2 = 7.4 species, etc.

3. Results and Discussion

3.1.1. Analysis of species diversity in different climate regions

The British climate subdivides into 17 climate zones using the combinations of temperature and wetness defined by Rivas-Martinez and Rivas-Saenz (1996) (Figure 1a). Twelve of these zones contained significant numbers of subcompartments (Figure 1b).

Statistical analysis (correspondence analysis and hierarchical cluster analysis) showed significant overlap between zones in the composition and abundance of species and that zones could be aggregated to form four distinct climate regions each with distinct mix of species (Figure 1c and Table 2). Forty-six percent of subcompartments occur in the cool-humid region, followed by 38% in the cool-wet region; only 10% are found in the warm-dry and 6% in the cold-wet regions (Table 2).

The warm-dry and cool-humid regions, which together contain 56% of subcompartments, had maximum species richness and the highest Shannon diversity indices, which are equivalent to just under 12 equally abundant species. Richness remains close to 20 in both the cool-wet and cold-wet regions that make up 44% of all subcompartments, but diversity is much less and is equivalent to just over six equally abundant species reflecting the saturation of available planting sites by a few species. The composition of the most abundant species in each climate region is shown in Table 3 and is discussed in more detail in the following section.

3.1.2. Estimating species climate space, defining species climate types, and analysing potential substitution.

Outlining the climate regions of high abundance using ellipses suggested the twenty species can be grouped into four categories of species climate types (Figure 2). The main abundance regions of three cool species (Figure 2a) span most of the wetness ranges, but are predominantly confined to the cool temperature range. In contrast, regions for five warm species mostly occupy the warm zone, and the dry and humid wetness zones (Figure 2b). The remaining 11 species span the complete temperature range, but separate into two groups depending on the wetness range covered. Eight extend from the Very Dry to the Wet zones (Figure 3c), while a further four are pan-climatic in that they extend into the Very Wet and so are abundant in all the zones of Britain (Figure 2d).

The composition of the most abundant species in each of the climate regions is made up of a mix of different climate types of species (Table 3). The warm-dry and cold-wet regions form the climate extremes in Britain, and the cool-humid and cool-wet can be considered as transition climate regions in between the extremes.

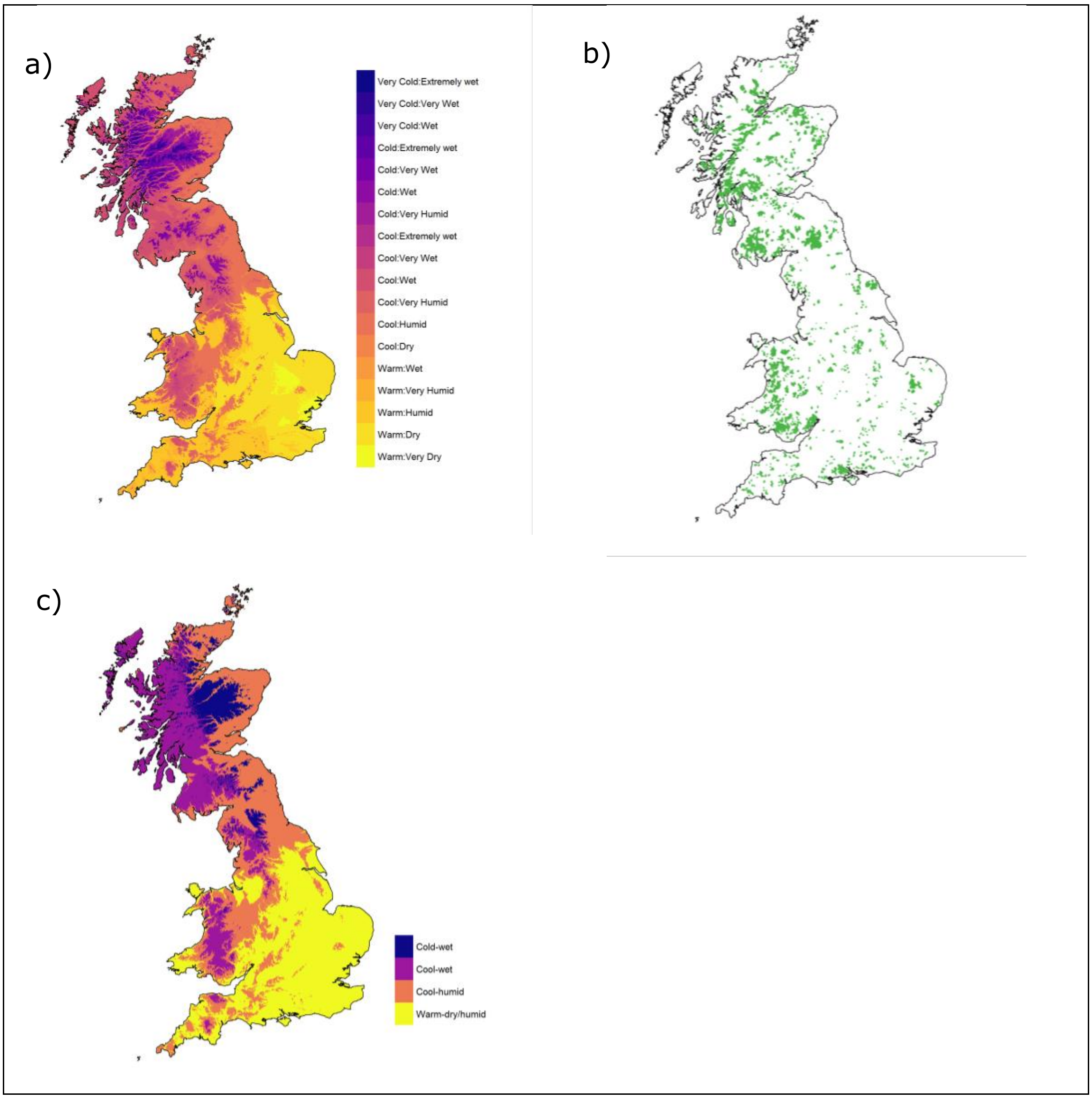

Figure 1. a) Climate zones of Britain based on the temperature and wetness categories of Rivas-Martinez & Rivas-Saenz, (1996), b) locations of subcompartments, c) the four climate regions that are aggregated from climate zones that have similar patterns of species abundance within them.

Table 2. Species diversity in the main climate regions of Britain. Climate regions are aggregated from climate zones that have similar patterns of species abundance within them.

Climate region	Constituent climate zones	Percentage of PFE sub-compartments	Number of most abundant species	Number of other species	Species richness	Shannon diversity index	Equivalent species
Warm-dry	Warm:Dry Warm:Humid	10	17	3	20	2.46	11.7
Cool-humid	Warm:VHumid Cool:Humid Cool:VHumid	46	15	5	20	2.46	11.7
Cool-wet	Cool:Wet Cool:VWet Cool:ExWet Cold:VWet Cold:ExWet	38	9	11	20	1.86	6.4
Cold-wet	Cold;VHumid Cold:Wet	6	7	12	19	1.81	6.1

Table 3. Composition of main species classified by climate type in each climate region. Species coloured red currently have restricted use because of fungal diseases, and pink have an uncertain future because of developing disease situations.

	Species climate type			
Climate region	**Warm**	**Cool**	**Dry-Humid**	**Humid-Wet**
Warm-dry	AH,BE, CP, OK, SC		DF, EL, GF, LC, RC, SP, SY, WH	BI, HL, JL, NS
Cool-humid		LP, NF, SS	DF, EL, GF, LC, RC, SP, SY, WH	BI, HL, JL, NS
Cool-wet		LP, NF, SS	WH, GF	BI, HL, JL, NS
Cold-wet		LP, NF, SS		BI, HL, JL, NS

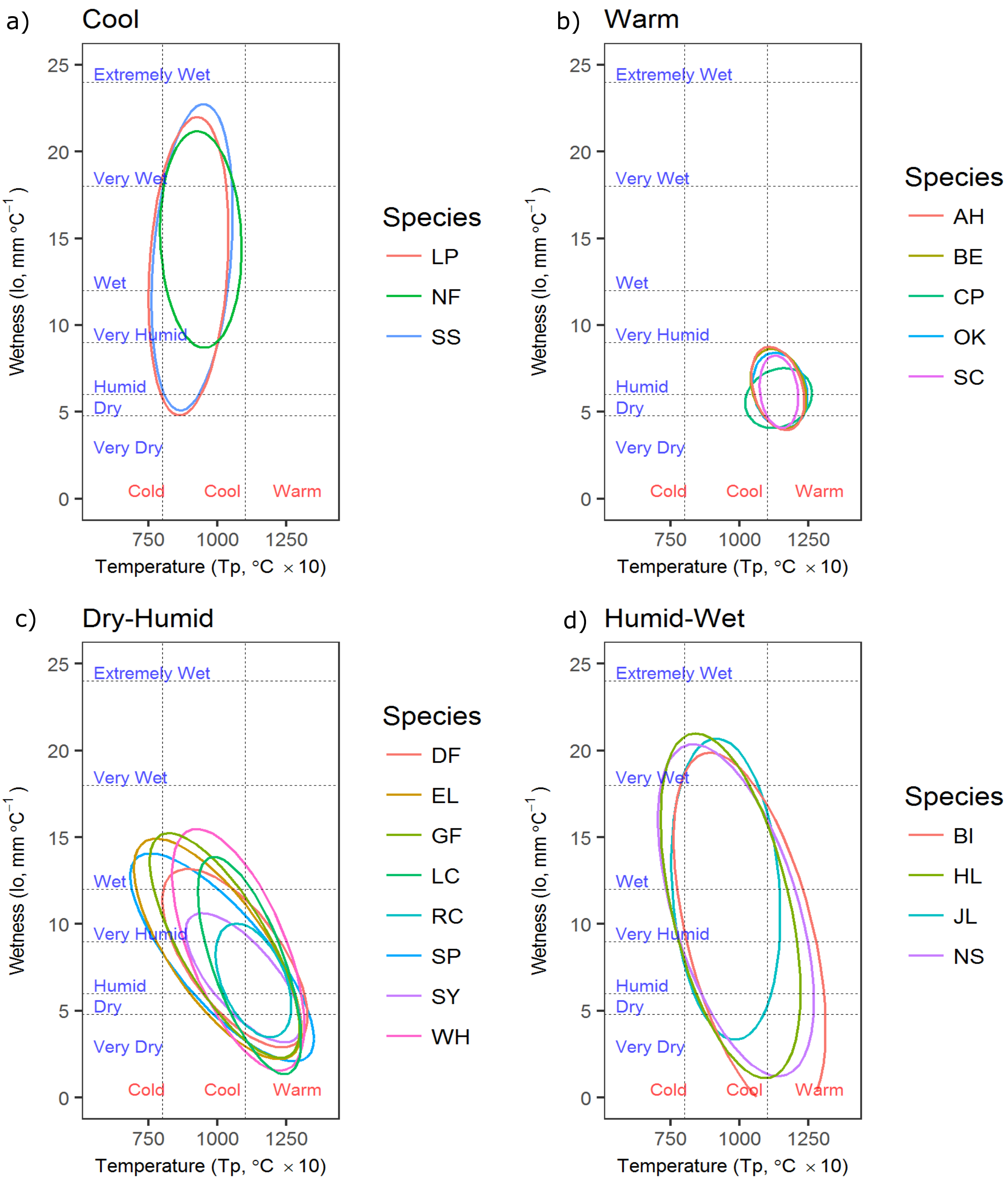

Figure 2. Climate space regions of 20 species drawn as ellipses fitted around the areas of greatest abundance in climate space (Note: species still occur outside these regions but at lower abundance). Species are categorised by the dominant region of abundance within climate space: a) cool: species absent from Warm zones, b) warm: species predominantly found in Warm zones, c) dry-humid: species that occupy all thermal zones and are most abundant in drier wetness zones, and d) humid-wet: species that extend into the Very Wet.

The four humid-wet species such as birches with their broad temperature and wetness amplitudes occur in all four climate regions, while the presence of other three types varies with region. The warm-dry region has the highest number of abundant species (17) containing in addition to the four humid-wet species, five warm species which are predominantly broadleaves, and eight dry-humid species such as Douglas-fir. Diversity is also high in the cool-humid region which contains the same dry-humid and humid wet-species as in the warm-dry, but the warm species types are now replaced by three cool species which includes Sitka spruce. In the wetter cool-wet region, cool and humid-wet species types remain abundant, but the number of abundant dry humid species is reduced from eight species to just two. The cold-wet is dominated by three cool species types and the four humid-wet types. In all regions, species diversity is of course reduced if species affected by pests and diseases (shown in red font in Table 3) are subtracted from the inventory. The impact is especially high in the low diversity cool-wet and cold-wet regions.

The warm-dry and cool-humid regions are reasonably diverse with a mix of principal and secondary species although there are shortfalls in certain species groups like pines which require research to find alternatives. Diversity in the important cool-wet and cold-wet regions is much lower but richness is high implying that there is scope for developing some of the low-abundance secondary and plot-stage species for wider use. The size of the cool-wet and cold-wet regions and the importance of species like Sitka spruce make increasing diversification a priority for research in these regions, even though their climates will shift in the future (see below).

Species that overlap in climate space can potentially substitute for each other and the proportionate area of overlap between the high abundance regions of pairs of species was calculated as a substitution index. Within each overlap zone, the extent to which species occur on similar soil groups was also compared statistically as a subsidiary test of substitutability. The overall extent of species substitution using both climate and soil overlap criteria is summarised in Figure 3. Species that occur predominantly in the warm-dry region are often mutually interchangeable, though some combinations differ in abundance on different soil groups. For example Corsican pine is climatically overlapped by 12 species, but two of these, ash and oaks, differ in soil affinities within their respective overlap regions (variation of abundance with soils is presented in more detail in Jinks, (2017)) . In contrast, species occupying cool and cold regions are overlapped by fewer species, reflecting the lower diversity in these zones. For example, Sitka spruce is overlapped by 5 species which have similar patterns of abundance across soil groups; however three of these species (Japanese and hybrid larches, and lodgepole pine) have restrictions on use due to diseases.

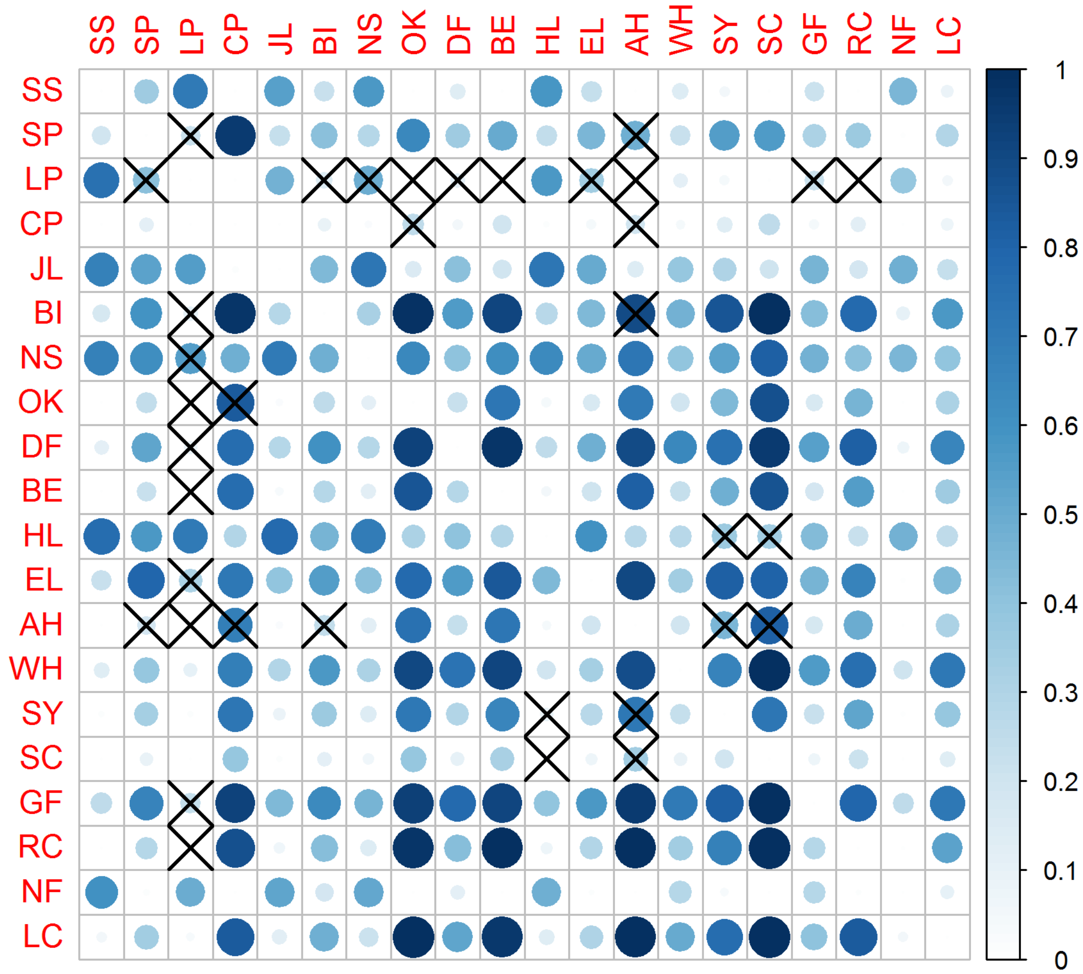

Figure 3. Graphical matrix summarising the proportions of climate space overlapped by pairs of species. The colour and size of a point indicates the proportion of the climate space of species listed at the head of the columns that is overlapped by the species listed in the rows; the darker and larger the point the greater the overlap in climate space which implies substitutability. Within the overlap regions, species may or may not occupy similar soil types and cells with crosses indicate species pairs with dissimilar patterns of abundance by soil groups.

3.1.3. Future changes in climate zones

Summaries of the future climate of subcompartment locations under different emissions scenarios in the 2050s show significant shifts (Figure 4). The climate of many subcompartments shift to the next warmest temperature zone, hence compartments presently in the cold zone shift to a cool climate, and many cool compartments shift to the

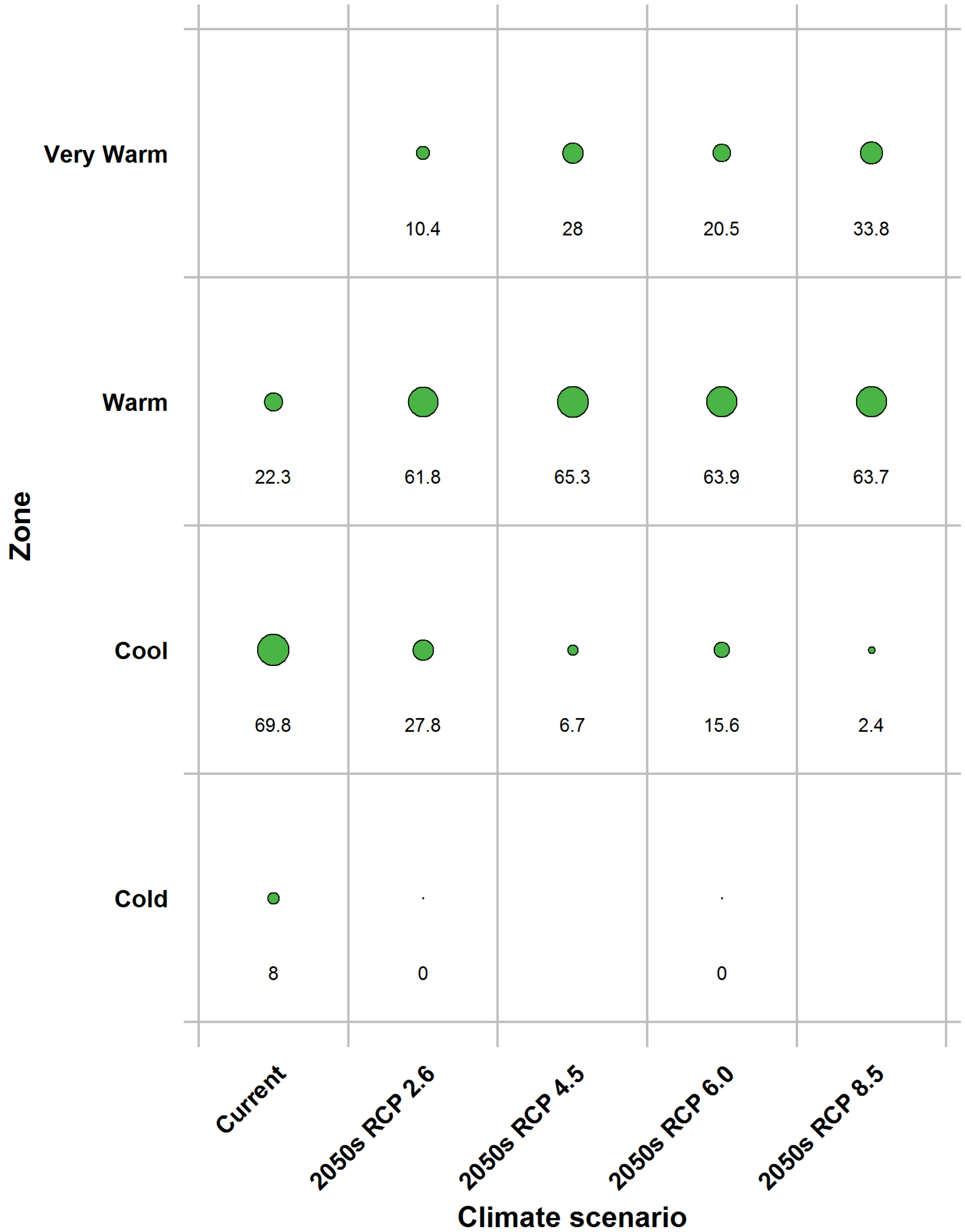

Figure 4. The percentage distribution of abundance of subcompartments between temperature zones in the current climate and in future climates derived from the HadGEM2-ES Global Circulation Model for four increasing greenhouse gas concentration scenarios (RCP, Representation Concentration Pathway).

warm zone. The present warm zone also shifts into a new zone for Britain, the Very Warm that by the 2050s could cover between 10 and 33% of subcompartments depending on the emissions scenario. The implications of this novel climate for species choice should be a priority for further research and be focussed on suitable plot and specimen stage species. The temperature range, together with its wetness zones (not shown in this report) of this novel zone has analogues in southern Europe as well as other regions of the warm temperate regions of the world (Figure 5). Tree species in these climate analogue regions are candidates for evaluation of trees for future forestry and are the subjects of scrutinising in tree collections.

Figure 5. Current regions of the world with annual temperatures similar to the Very Warm category in Figure 4.

4. Conclusions and Recommendations

Two situations are identified where increases in species diversity are needed. Firstly, in the present climate where impacts of pests and diseases are eroding the diversity of useable species, particularly in the wet climate regions of Britain that are dominated by Sitka spruce. Secondly for the future climate where model projections suggest significant shifts in climate zones that will encompass existing species and will require continued evaluation of new species and provenances for use in novel warmer climates.

Three work streams are proposed to address these issues.

1. **Increasing diversity in the present climate**

   1.1. Assess the extent to which underutilised principal and secondary species can substitute for Sitka spruce using climate space overlaps within the Wet zones.

1.2. Assess and review the performance of principal, secondary species and plot-stage species (e.g. Pacific silver fir) with Sitka spruce in existing species trials in the Wet zones.

1.3. Continue investigations on increased use of secondary species, including:

- examining provenance recommendations by re-assessing surviving provenance trials in all climate zones,
- pest and disease susceptibilities and limitations,
- silvicultural deployment (establishment methods, mixtures, etc.).

Priorities include secondary species such as western red cedar and western hemlock.

2. The suitability of current species in future climates

2.1. Assess the extent to which the existing warm species can grow in future warm climates of Britain by analysing the extent to which the full climate space of species overlaps future projected climate. This will involve constructing climate space models using data from the complete geographic range of species, including subdivisions for provenances if available.

3. Identifying species for future climates

3.1. Refining the demarcation of future climate zones using projected climate data from several GCMs.

3.2. Match future climate zones to current climates elsewhere in the world and carry out inventories of native and introduced species in the analogue regions and identify potential forestry species (candidate species). The focus will be on filling gaps from lesser known regions of the world and seeking drought tolerant species like pines, cedars, etc.

3.3. Review existing species trials and tree collections to summarise growth and performance of candidate species under current conditions.

3.4. Construct tolerance niches for candidate species to be used to assess tolerance within the full range of future climates in Britain.

3.5. Establish new comparative species and provenance trials of the most promising candidates in selected climate zones that are currently close to the future climate.

5. Acknowledgments

I would like to thank the staff of the FC Inventory, Forecasting and Operational Support team for maintaining and providing the superb subcompartment database without which this work would not be possible. I also thank Gary Kerr, Matt Parratt and Ian Willoughby for helpful discussions during the evolution of the approaches used in this study.

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