Research & Evidence

The Wildlife Trusts

Temperate rainforests in the UK and climate change: a pilot study

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Bringing **Wildlife** Back

Summary

Temperate rainforests are globally-rare habitats of which fragments remain in western parts of the UK. They are fundamentally defined by climate, so are potentially exposed to the effects of climate change. This report presents a pilot assessment of the potential effects of climate change on temperate rainforests in the UK. It uses a definition of the climatic suitability for temperate rainforests and a set of seven climate indicators relevant to their sustainability. Climate change impacts through the 21st century are assessed for different levels of global warming ranging from an increase in global average temperatures of just 1.5°C by 2100 to the increases of more than 5°C in emissions pathway RCP8.5. The climate scenarios are based on the UKCP18 climate projections and are applied at a spatial resolution of 12x12km across the UK.

The three key conclusions are: (i) risks to the viability of temperate rainforests depend strongly on emissions pathway and, for a given pathway, the range of climate projections used, (ii) the key drivers of climate change-induced risk to temperate rainforests increase across all of the UK apart from northern Scotland, and (iii) envelopes describing climatic suitability for temperate rainforest do not provide a robust means of assessing future climate risks because impacts are very sensitive to the (unknown) upper temperature limit.

Whilst the assessment has shown that climate change has the potential to adversely affect temperate rainforest habitats across most of the UK, it has also identified four key uncertainties and knowledge gaps affecting the development of policy towards temperate rainforest restoration. There is a need for (i) better understanding of where temperate rainforests can currently be found, (ii) better understanding of their climatic limits and the key climate drivers, (iii) a more detailed analysis with a wider range of climate projections, (iv) better understanding of how climate change would differentially affect different species in temperate rainforests and therefore rainforest character, and (v) a detailed assessment of how changes in rainforest microclimates are linked to changes in local and climate.

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KEY INFORMATION

This paper is the result of work carried out in 2024, by Professor Nigel Arnell, from the Department of Meteorology at the University of Reading, under contract to the Royal Society of Wildlife Trusts.

It presents a pilot assessment of the potential effects of climate change on temperate rainforests in the UK.

It has been published by The Wildlife Trusts as part of a strategic commitment to generate, share and use good evidence, and to be open about the data, evidence and reasoning that underpin the federation's decisions, policies and actions.

This paper has been published as part of a series launched in 2025, to fulfil a commitment made in The Wildlife Trusts' Collective Framework on Data, Research & Evidence, a copy of which can be obtained by e-mailing evidence@wildlifetrusts.org

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The DellaSala Rainforest Data are available at https://databasin.org/datasets/e60e7ca203b74f06b1ba027a4a326406/

Find out more at: www.wildlifetrusts.org/

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1. Introduction

Temperate rainforests are globally-rare habitats occurring in fragmented pockets in western parts of the UK. They are broadly characterised by humid conditions and mild temperatures throughout the year and consist of a characteristic mix of deciduous and evergreen trees, lichens and bryophytes (mosses and liverworts). The extent of temperate rainforests in the UK has reduced over the long-term through clearance and chronic overgrazing, and they are threatened by invasive species, disease and future changes to how woodlands are managed. They are defined by climate and are therefore also potentially threatened by climate change – particularly if that climate change leads to hotter, drier summers.

This report describes a pilot assessment of the implications of future climate change for the areas of the UK with climatic conditions suitable for temperate rainforest. There are two ways of assessing the implications of climate change for temperate rainforest (or indeed any vegetation type). One is to assess changes in the climatic suitability for temperate rainforest. This requires an understanding of the climatic conditions which enable temperate rainforest – its 'climate envelope'. The second is to assess changes in relevant climatic conditions in areas currently covered with temperate rainforest, or where temperate rainforest might be developed – for example through planned planting – in the future. This approach allows consideration of a wider range of climate characteristics but requires information on the current and future locations of temperate rainforest. Both approaches are followed here.

2. Definitions & Indicators

2.1. Climate Suitability for temperate rainforests: climate envelopes

Temperate rainforests are characterised by a distinct assemblage of epiphytic lichens, understory bryophytes and fungi (Ellis, 2016; Averis, 2023), with a variety of tree species including ash, hazel, oak and Scots Pine: the trees are typically – but not always – stunted. They require wet or humid conditions through the year, cool summers (so they do not dry out and are not affected by fire) and mild winters.

Climatic conditions therefore constrain where temperate rainforests can occur. Both Ellis (2016) and Averis (2023) used two indicators to define the climatic conditions suitable for temperate rainforest in the UK. The first is the climatic envelope defined by Alaback (1991), which is based on the characterisation of temperate rainforest climates at the global scale as having cool summers and wet weather all year round.

The specific climatic criteria defined by Alaback (1991) are:

- Average annual precipitation greater than 1400mm
- At least 10% of this precipitation falling in the three summer months
- Cool frequently overcast summers with July (Northern Hemisphere) average temperature less than 16°C
- A dormant season caused by 'low' temperatures.

After considering three different definitions of 'low' temperature, Averis (2023) concluded that a threshold of 2°C best characterised the range of temperate rainforest habitats in Britain.

The second indicator describes the 'oceanity' of climate using Amann's (1929) index of hygrothermy:

$$H = \frac{(PxT)}{t_h - t_c}$$

where P is average annual precipitation (in cm), T is average annual temperature (in °C), and th and tc are the average temperature of the hottest and coldest months respectively. The smaller the range in temperature between the hottest and coldest months, the larger the index H and the greater the degree of 'oceanity'. Ellis (2016) defined a 'hyperoceanic' zone with an index greater than 150, and an 'oceanic' zone with an index between 100 and 150. Variations on this indicator (Averis, 2023) show similar geographical patterns. Amman's index has been widely used to explain the distribution of lichens and bryophytes (Eliis, 2016), but it does not clearly describe the climatic conditions that influence species composition. Averis (2023) therefore concluded that it provided a 'less meaningful' index of temperate rainforest occurrence than the Alaback criteria.

Averis (2023) considered the number of rain-days as an alternative measure of wetness to total annual rainfall. There is a close association between the two, but Averis concluded that an indicator based on rain-days included parts of Britain and Ireland where temperate rainforest does not currently occur and does not appear to have occurred in the past. He also looked at summer potential water deficit, as an indicator of summer dryness, which shows a similar geographic distribution to total rainfall. Areas with low summer potential water deficit are very similar to areas with high rainfall.

DellaSala et al. (2011) used the MaxEnt bioclimatic envelope model with 11 climate-related parameters (describing various dimensions of temperature and rainfall) and data from six regions around the globe with known temperate rainforest to build a model describing probability of rainforest occurrence and therefore the extent of the temperate rainforest biome. The boundaries on this multi-dimensional envelope are not publicly available, so it is not feasible here to see how this envelope varies with climate change. The construction of the DellaSala et al. (2011) envelope did not use any data from the UK.

In principle it may be possible to define climate envelopes for individual temperate rainforest indicator species. However, in practice temperate rainforests are defined by an assemblage of species, each of which will have different climate envelopes.

Climate envelopes are widely used to characterise the distribution of specific vegetation types or ecosystems, and to assess the effect of climate change on their distribution. However, there are three main problems with climate envelopes. First, they need to be defined using relevant climate characteristics. They are usually based on average climate (usually temperature and rainfall), but it is possible that some other dimension of climate is more relevant, such as humidity or the chance of summer drought.

Second, climate envelopes are typically defined on the basis of the current distribution of a vegetation type (although they could in principle be defined from physiological requirements). A vegetation type may not occur within a specific combination of climate characteristics simply because that combination does not currently occur. An apparent climate limit for a vegetation type may therefore arise simply because no places currently have climate outside the limit: if they did, then the vegetation type might occur there.

Third, use of climate envelopes to determine changes in suitability due to climate change implicitly assumes that the vegetation type is not able to adapt to a changing climate. This is particularly important when the vegetation type is characterised by a range of possible assemblages of species, and whilst individual species might become more or less abundant the overall vegetation type remains broadly the same.

Silver et al. (2024) assessed the effects of climate change on the climatic suitability at the global scale for temperate rainforest by calculating the change in some of the climate variables defining the current biome: they used the DellaSala et al. (2011) envelope to identify current temperate rainforest. They defined a loss of biome as occurring when either annual precipitation or warm season temperature or the proportion of annual rainfall occurring during the warm season at a location currently identified as having a suitable climate changed in an adverse direction (drier, warmer and lower respectively) by more than three times the standard deviation of that variable across a region.

2.2. Climate characteristics relevant to temperate rainforests

Temperate rainforests are characterised by a distinct assemblage of epiphytic lichens, understory bryophytes and fungi (Ellis, 2016; Averis, 2023), with a variety of tree species including ash, hazel, oak and Scots Pine: the trees are typically – but not always – stunted. They require wet or humid conditions through the year, cool summers (so they do not dry out and are not affected by fire) and mild winters.

This approach requires the definition of climate characteristics that affect the viability and sustainability of temperate rainforests, and information on the locations where temperate rainforests exist or are planned to exist.

As outlined above, temperate rainforests are characterised by mild conditions throughout the year and persistently wet or humid conditions. A drier climate for at least part of the year is the most obvious challenge to temperate rainforests. Relevant climate indicators include summer (June to August) rainfall, summer vapour pressure deficit (a measure of humidity), maximum potential soil moisture deficit, the moisture index used by Ellis & Eaton (2021), and the risk of drought. Potential soil moisture deficit is the accumulated difference between potential evaporation and rainfall, and the PSMD index is defined as the largest difference in the year (Arnell & Freeman, 2021).

Ellis & Eaton's (2021) moisture index, used in their assessment of the effect of microclimate on the distribution of cyanolichens in temperate rainforests, is:

$$M = \frac{P}{VPD}$$

where P is the precipitation in mm in the three driest months in the year, and VPD is the average vapour pressure deficit in those months in Pa. The vapour pressure deficit is the difference between vapour pressure and the saturation vapour pressure at temperature T. Here, the moisture index is calculated over the period June to August for the sake of consistency, although this is not necessarily the driest three-month period everywhere. Although a low index characterises 'drier' conditions (low rainfall or high vapour pressure deficit), the moisture index does not have a clear physical interpretation.

Drought is here characterised by the 3-month Standardised Precipitation Index (SPI), which is calculated from rainfall accumulated over three months (Arnell & Freeman, 2021). A 'drought' is here defined as an SPI index of less than -2, which occurs in 6.7% of months over a reference period (i.e. in 24 months over a 30-year period).

The effect of higher temperatures on temperate rainforests – other than through increased drying – is less clear. Whilst some species characteristic of temperate rainforests in the UK have upper thermal limits, others do not, so higher temperatures in themselves may not substantially alter the characteristics of temperate rainforest. However, summer (June to August) average temperature is used here as a potential indicator of climate change challenges to temperate rainforest.

Although temperate rainforests are too wet to be affected by wildfire (and indeed a lack of wildfires is a diagnostic feature), higher temperatures and drier conditions are likely to increase wildfire risk in the UK (Arnell et al., 2021a). Wildfire danger is here characterised by a version of the UK Met Office Fire Severity Index (MOFSI), used operationally to describe fire risk: specifically, fire danger here is characterised by the average number of days with 'very high' danger (Arnell et al., 2021a). It is recognised that the MOFSI system is based on the Canadian fire danger system so is not necessarily ideal for UK conditions, but it does provide an indication of changing wildfire danger.

This perspective uses some of the same indicators as Silver et al. (2024) – specifically summer temperature and summer rainfall - but does not seek to categorise changes in the indicators to represent change in suitability. Instead, it provides a more nuanced description of the challenges facing temperate rainforests.

2.3. Where are temperate rainforest habitats in the UK?

There is currently no definitive database locating actual temperate rainforests in the UK. Temperate rainforests are not defined specifically in the National Vegetation Classification (NVC). The most common NVC communities in temperate rainforest are W11 and W17 (Averis, 2023), but neither of these are unique to rainforest. The 'Lost Rainforests of Britain' campaign (https://lostrainforestsofbritain.org/; Shrubsole, 2022) developed an online database of rainforests across Britain through a combination of interpretation of public data sets and submissions from the public.

Whilst most of the identified fragments are within the potential bioclimatic envelope (whether defined by the Alaback criteria or oceanity), some are well outside. This may be because the micro-climatic conditions in the fragments do actually fall within the envelope, or because the plants and fungi living within them have broader physiological needs than represented by the envelope, or due to mis-identification.

Ellis (2016) and Ellis & Eaton (2021) define locations which could have temperate rainforest as places with Amman's index of hygrothermy greater than 100 ("oceanicity"). As noted above, the DellaSala et al. (2011) envelope rules for temperate rainforest are not publicly available. There is, however, an open global data base containing locations with suitable temperate rainforest climate as defined by the rules, at a spatial resolution of 0.0416x0.0416o (approximately 2.5x4.6km in the UK).

Figure 1 shows these various definitions. The Alaback and oceanicity maps show suitable locations calculated at the 1x1 and 12x12km scales. Because the 1x1km data are at too fine a scale to map here, the 1x1km maps show the proportion of the 12x12km containing suitable 1x1km grid squares. 39,334 of the 245,077 1x1km grid squares (16%) are suitable for temperate rainforest. The 12x12km resolution data miss some coastal areas and some areas of suitable climate in southwest Scotland, the south Pennines and parts of Northern Ireland, but the distributions are broadly similar. 298 of the 1711 12x12km grid squares (17%) are suitable – based on climate averaged over 12x12km - but 573 of these 12x12km grid squares (33%) contain at least 1km² of suitable climate. There are currently 68,532 1x1km and 510 12x12 km grid squares with a hygrothermy index greater than 100 (28% and 30% respectively). 633 (37%) of the 1711 12x12km grid cells have at least 1km² with an index greater than 100.

The Lost Rainforests panel plots symbols at the centre of each identified fragment: it does not represent the area covered by temperate rainforest. The DellaSala et al. (2011) map of temperate rainforest climates includes larger parts of upland Scotland and England than the other definitions and does not include southwest England.

Averis (2023) concludes that the Alaback criteria provide a more reasonable definition of climatic suitability for temperate rainforest than oceanicity, so this is used here to define the current geographic extent of temperate rainforest habitats.

3. Data and climate scenarios

3.1. Reference climate data

Current climatic conditions are based on the UK Met Office HadUK-Grid observed data set (Hollis et al., 2019) at 1x1km and 12x12km resolutions, averaged over the period 1981-2010. It is recognised that this period already includes some climate change, so does not necessarily represent the climatic conditions in which current temperate rainforests were established. A later reference period would include more climate change.

The HadUK-Grid data set describes the macroclimate across an area, and even at the 1x1km resolution there may be very substantial variation in microclimate in topographically heterogeneous landscapes. Many current fragments of temperate rainforest, particularly in the southwest, occur in deeply incised river valleys which may be considerably more sheltered and humid than the surrounding area. Some of the fragments of temperate rainforest identified in the Lost Rainforests of Britain database may potentially be in locations where the microclimate is very different to the macroclimate.

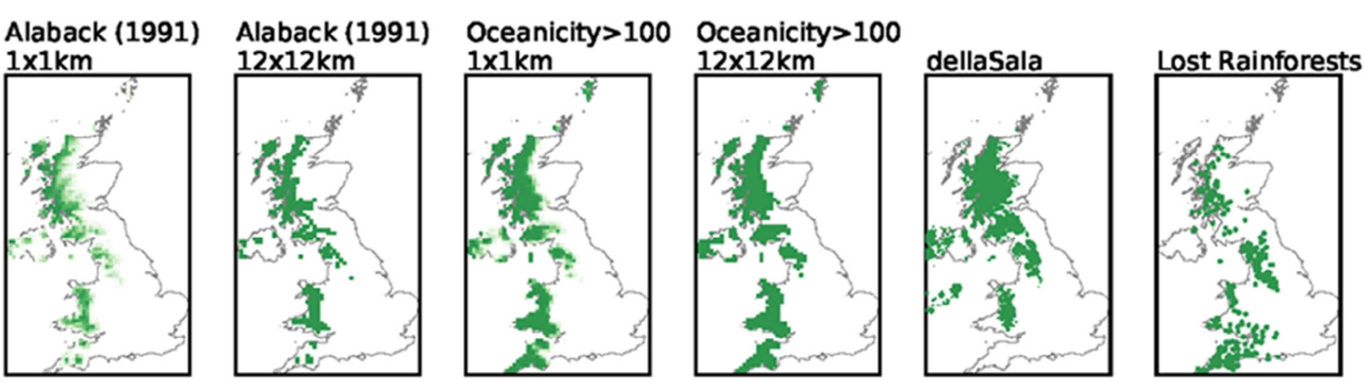

Figure 1: The current distribution of temperate rainforest habitats across the UK, using different definitions. The Alaback criteria and hygrothermy index are calculated at the 1x1km and 12x12km resolutions: the 1x1km data are aggregated to the 12x12km grid, and the maps show the proportion of the 12x12km grid with suitable 1x1km grid squares. The Lost Rainforests map shows the locations of identified fragments: the dots are not proportional to the size of the fragment, so this map does not show area.

3.2 Climate scenarios and their application

This pilot assessment uses five sets of climate projections based on the UKCP18 global strand HadGEM PPE-15 simulations (Lowe et al., 2018), representing five different future emissions pathways. One is the original UKCP18 RCP8.5 pathway, which assumes very high emissions: the global average temperature by 2100 is projected to be between 5 and 6.3°C above pre-industrial levels. The other four represent pathways consistent with increases in global mean temperature of 1.5, 2, 3 and 4°C above pre-industrial levels by 2100. They are produced by rescaling the original UKCP18 HadGEM PPE-15 RCP8.5 projections. Each set of projections consists of 15 equally plausible ensemble members which represent uncertainty in how climates across the UK will change for a given pathway of emissions.

Note that the uncertainty range across the 15 ensemble members is to be interpreted slightly differently between the different pathways. For the RCP8.5 pathway, the range includes uncertainty in the global average temperature change for a given level of forcing, whilst for the other pathways the global average temperature change is constrained. There is relatively little difference at the UK scale, but the uncertainty range for the temperature-based pathways is slightly smaller than for the RCP8.5 pathway.

The increases in temperature in the UKCP18 global strand HadGEM PPE-15 RCP8.5 projections are larger than the increases in the global strand CMIP5 RCP8.5 projections and are towards the higher end of the projected increases in the UKCP18 probabilistic RCP8.5 projections. They therefore represent the top end of the range of potential changes. The rescaled HadGEM PPE-15 and CMIP5 projections, however, are much closer to each other.

The projections are applied to the 12x12km observed 1981-2010 climate using a transient delta method (see Arnell et al., 2021b). In summary, time series of monthly model anomalies from the model 1981-2010 average climate are smoothed, and these anomalies are applied to a repeated 1981-2010 time series to create a perturbed time series. In each emissions pathway and ensemble member, the 1981-2010 climate is equal to the observed climate.

All the climate indices calculated here are calculated at each 12x12km grid square over rolling 30-year periods ending in 2100, with 1981-2010 as the reference period. The climate suitability index and oceanicity index are calculated from 30-year mean climate. The other indicators represent the average over 30 years from indicators calculated at daily (vapour pressure deficit, moisture index and fire danger index) or monthly time steps.

Average indices by administrative region are calculated by weighting each 12x12 km grid square by the number of 1x1km grid squares with climates currently (1981-2010) suitable for temperate rainforest as defined using the Alaback (1991) criteria.

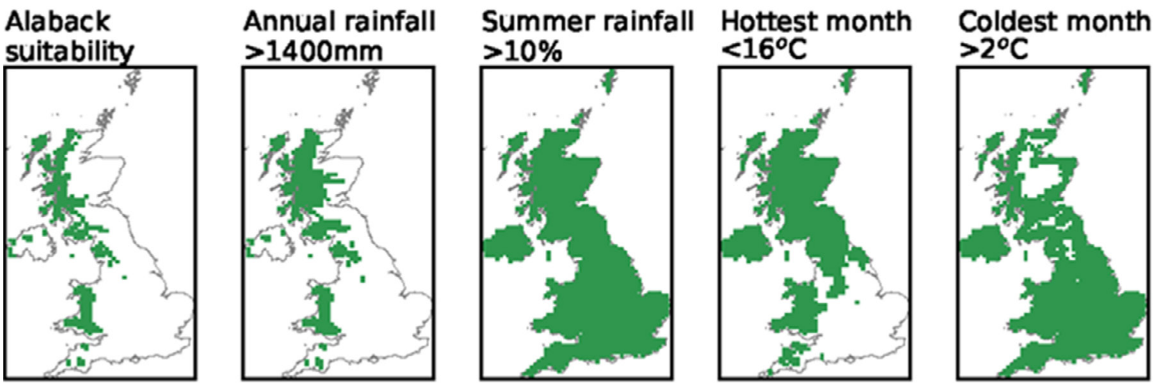

Figure 2: The factors determining the current distribution of temperate rainforest climates, using the Alaback (1991) criteria, at the 12x12km resolution.

4. Changes in suitability

4.1. Climate scenarios and their application

The current area with a suitable climate (according to the Alaback (1991) criteria) is almost entirely determined by the area with annual rainfall greater than 1400mm (**Figure 2**), limited in parts of highland Scotland by areas with the coldest month less than 2°C. The summer rainfall constraint does not affect the distribution (all of the UK currently has at least 10% of its rainfall during summer), and the hottest month temperature constraint is much less limiting than the rainfall constraint (all parts of the UK where the temperature of the hottest month is greater than 16°C have annual rainfall less than 1400mm).

4.2 Change in suitability: the Alaback criteria

Maps showing change in suitability across the UK through the 21st century under very high RCP8.5 emissions are shown in **Figure 3**, and **Figure 4** shows time series of the regional areas suitable for temperate rainforest under all five emissions pathways.

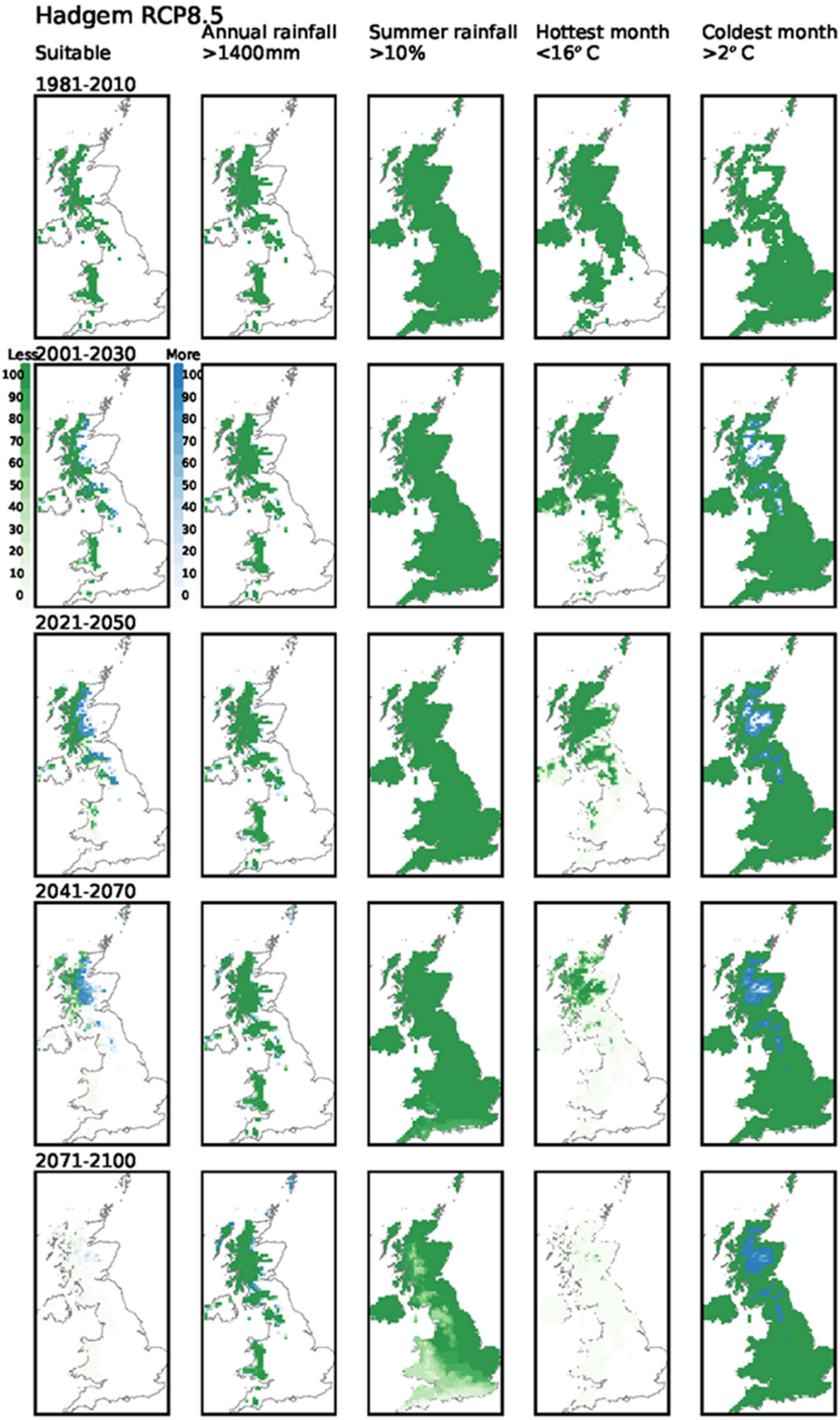

Figure 3: Change in climatic suitability and individual components through the 21st century, with RCP8.5 (very high) emissions and the UKCP18 HadGEM PPE-15 ensemble. Green shows areas which remain suitable or remain within the individual constraint in all 15 ensemble members. The blue shades show the proportion of ensemble members which become more suitable.

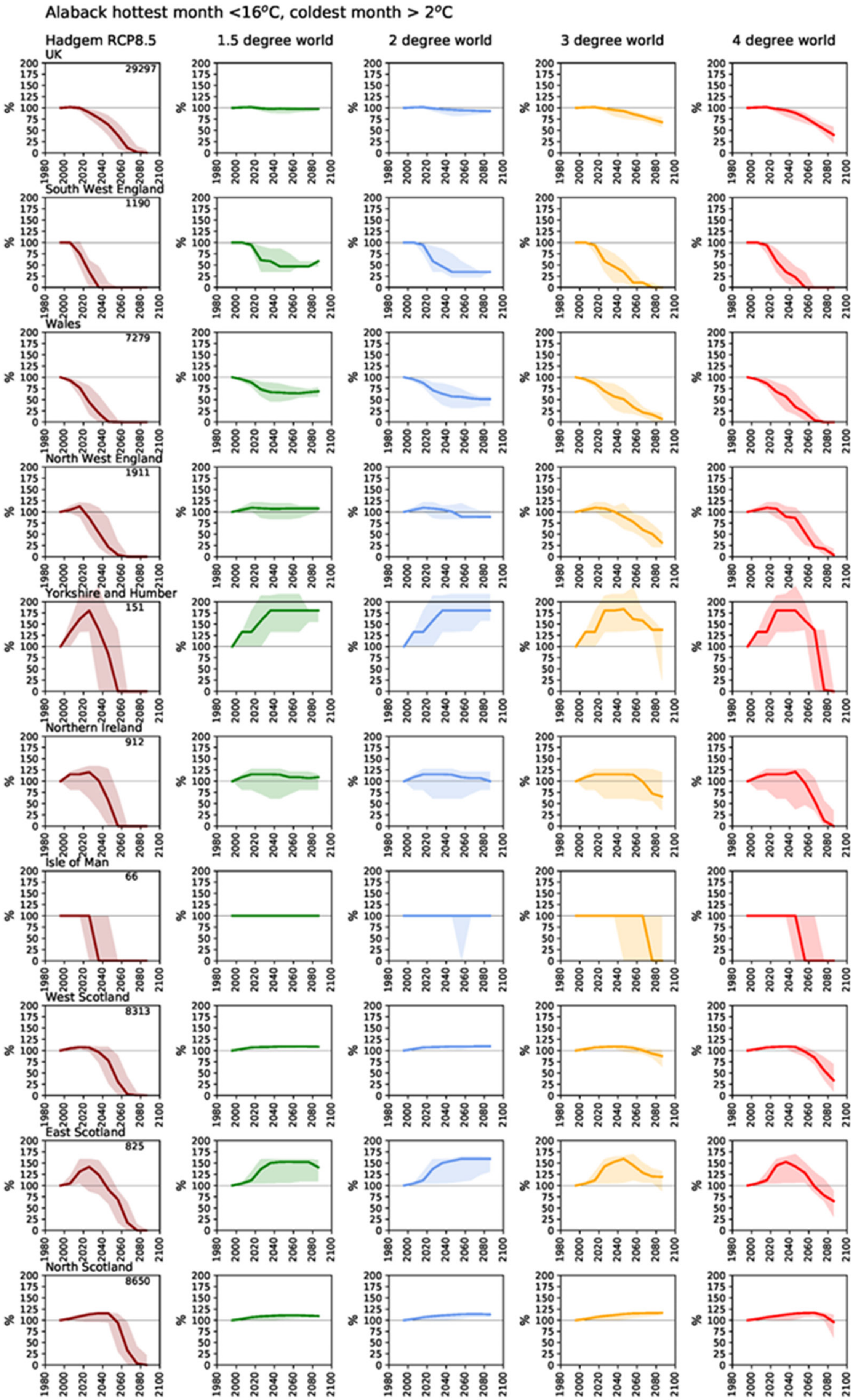

Figure 4: Change over time in the regional area suitable for temperate rainforest using the Alaback criteria, under thefive emissions pathways, the UKCP18 HadGEM PPE-15 ensemble, and with the hottest month temperature threshold of 16°C. Each plot shows the suitable area as a percentage of the area suitable with the 1981-2010 climate, and the number in the corner of the left-hand plots shows the area. Each plot shows the median plus range across 15 ensemble members.

With very high emissions, the area deemed suitable for temperate rainforest according to the Alaback criteria decreases so that there is virtually none by the 2080s. This is primarily because temperatures in the hottest month soon exceed 16°C across much of the UK. In Wales, southwest England and parts of northwest England the proportion of rainfall during summer also falls below the required threshold by the 2080s. Higher overall temperatures lead to less area constrained by low temperature, so suitability in some upland regions *increases* temporarily to the 2050s before being offset by the higher hot month temperatures. Note that if a lower cold month threshold is used to define suitability, then most of the areas that see an increase in suitability here would be deemed suitable in the current climate.

The reduction in areas deemed suitable for temperate rainforest are much lower with the other four pathways, even with a 4°C increase in global average temperature by 2100. This is primarily because the area with the temperature of the hottest month above 16°C increases by far less. However, even in a 1.5 or 2°C world the area suitable for temperate rainforest in southwest England and Wales is substantially reduced.

The area apparently suitable for temperate rainforest in the UK in the future depends primarily on the increase in temperature during the hottest month. However, the upper temperature threshold is uncertain. All the areas in the UK with rainfall more than 1400mm currently have temperatures of the hottest month below 16°C, so it is not obvious that 16°C is a real constraint. Using a higher threshold for the temperature of the hottest month implies that the area deemed suitable for temperate rainforest is less sensitive to climate change. With a threshold of 18oC, for example (**Figure 5**), there is little reduction in area suitable for temperate rainforest in 1.5, 2 or 3°C worlds – and an increase in the north. With a threshold of 20°C (**Figure 6**) there is no reduction even in a 4°C world. In the more extreme RCP8.5 scenario, a threshold of 20°C would mean that there is no reduction in suitability in Scotland.

The apparent sensitivity of climate suitability to climate change therefore depends strongly on the assumed upper temperature threshold for temperate rainforest.

Rising temperatures imply an increase in suitability in some areas currently below the cold temperature threshold (2°C). This apparent increase in suitability is short-lived, and dependent on the low temperature threshold.

Figure 5: Change over time in the regional area suitable for temperate rainforest using the Alaback criteria, under the five emissions pathways and with a hottest month temperature threshold of 18°C.

Figure 6: Change over time in the regional area suitable for temperate rainforest using the Alaback criteria, under the five emissions pathways and with a hottest month temperature threshold of 20°C.

4.3. Change in suitability: substantial changes in climate over the temperate rainforest biome

As outlined above, Silver et al. (2024) defined a loss of suitability for temperate rainforest as occurring where there were adverse changes in annual rainfall, summer temperature and the proportion of rainfall in summer. An adverse change was defined as greater than three times the standard deviation of these climate variables across all locations in a region currently suitable for temperate rainforest.

Silver et al. (2024) included the UK in a larger European region that also included temperate rainforest locations in Ireland, Norway, Switzerland, Austria and the Czech Republic. Their thresholds (inferred from their Figure 2) were approximately 1300mm, 5°C and 10 percentage points respectively for annual rainfall, summer temperature and the proportion of rainfall falling in summer. They estimated a reduction in the area in the UK with suitable climate of 60% (central estimate) over the period 2081-2100 with the SSP5-85 scenario (similar to RCP8.5).

The same basic approach was applied here, but with standard deviations calculated just across the grid cells in the UK with current climate meeting the Alaback criteria. These thresholds are approximately 1500mm, 4.3°C and 5.6 percentage points. The thresholds for the summer temperature and summer rainfall change are lower than used by Silver et al. (2024) because there is more variability across European temperate rainforest sites than across sites just in the UK.

Figure 7 shows the application of the Silver et al. (2024) approach over the grid squares with at least 1km² of suitable conditions under the current (1981-2010) climate. With RCP8.5, suitability declines rapidly to zero across the entire UK by the 2080s at the latest. This is due to the increase in temperature of more than three times the current standard deviation (i.e. an increase of more than 1.8-2.6°C). In a 4°C world suitability is reduced to zero across all but Scotland by the 2080s. Suitability declines after then 2060s across the UK in a 3°C world but is unchanged in the 1.5 and 2°C worlds.

The reduction in suitability in RCP8.5 is larger than calculated for the UK by Silver et al. (2024) under the similar SSP5-85 emissions scenario. This is partly because the thresholds calculated here are lower, and partly because the UKCP18 HadGEM PPE-15 RCP8.5 ensemble has increases in temperature that are at the top of the range across different climate models. Using the same thresholds as Silver et al. (2024) produces a similar reduction to Silver et al. (2024) in 2081-2100, but a larger reduction in earlier years.

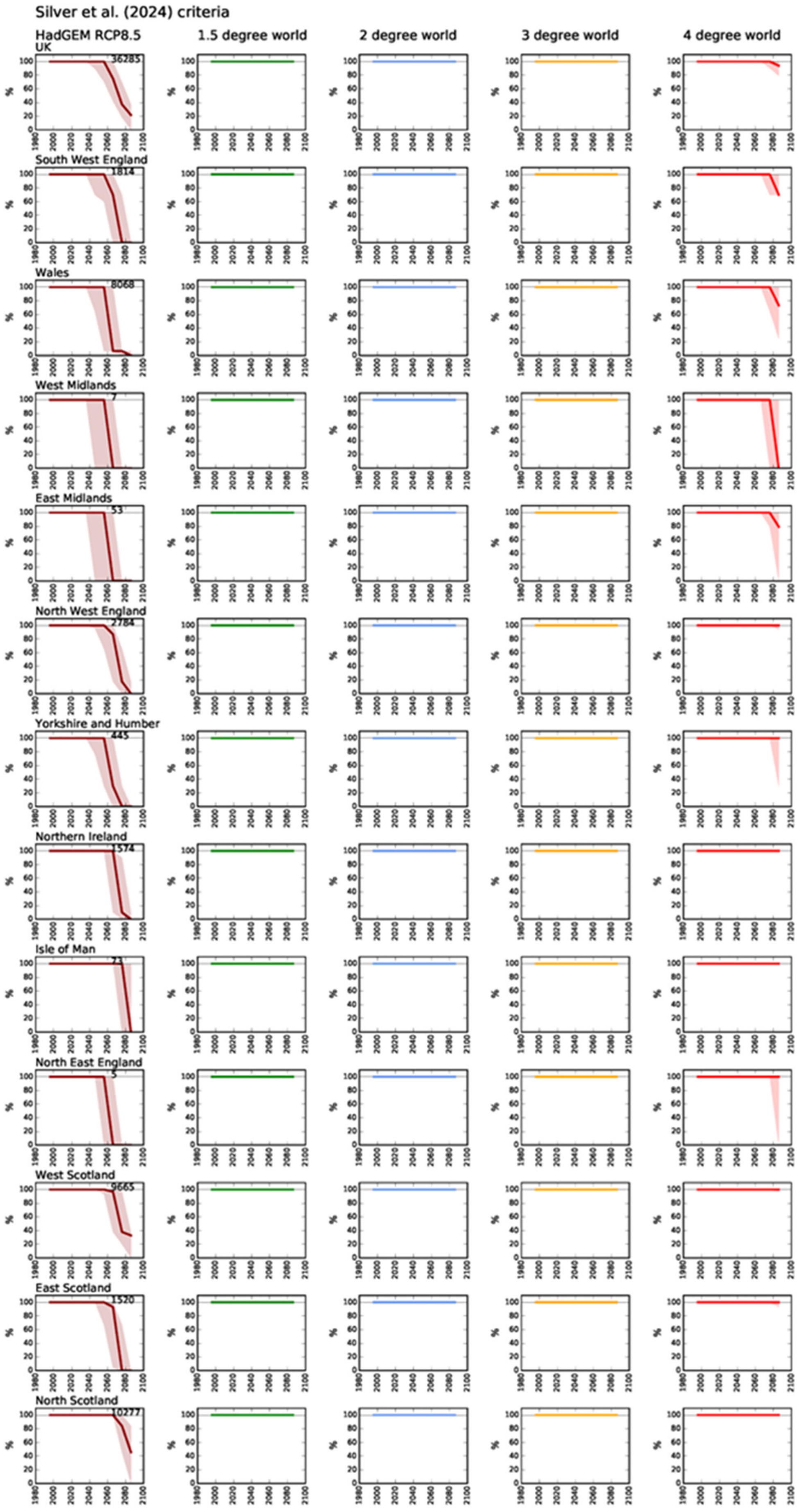

Figure 7: Change over time in the regional area suitable for temperate rainforest, using the Silver et al. (2024) criteria. Each plot shows the suitable area as a percentage of the area suitable with the 1981-2010 climate, and the number in the corner of the left-hand plots shows the area. Each plot shows the median plus range across 15 UKCP18 HadGEM PPE-15 ensemble members.

5. Change in relevant climatic characteristics

5.1 Changes in climate indicators

Maps of the median change in the seven climatic indicators are shown in **Figure 8:** the maps show only the 12x12km grid squares with at least 1km² of suitable conditions under the current (1981-2010) climate. Time series of regional average change are shown in **Figure 9**, where the 12x12km grid squares in a region are weighted by the area deemed suitable using the Alaback criteria under the current climate (results are very similar when weighting by the number of 1x1km grid squares with a hygrothermy index greater than 100).

The changes in the indicators are broadly similar across the UK, with the smallest changes in northern Scotland. Summer rainfall reduces, even in the 1.5°C world, and summer vapour pressure increases. The potential soil moisture deficit increases and the summer moisture index decreases – both indicating drier conditions in the future. The proportion of time in drought increases. Summer temperatures increase, and fire danger increases too, particularly in England and Wales after the 2050s.

Taken together, these indicators suggest that temperate rainforests across the UK – with the exception of northern Scotland – will face increasingly dry conditions during summer and a greater fire danger. The risks are strongly dependent on the future pathway of climate change, and the increases are small with pathways reaching 2°C or less by 2100.

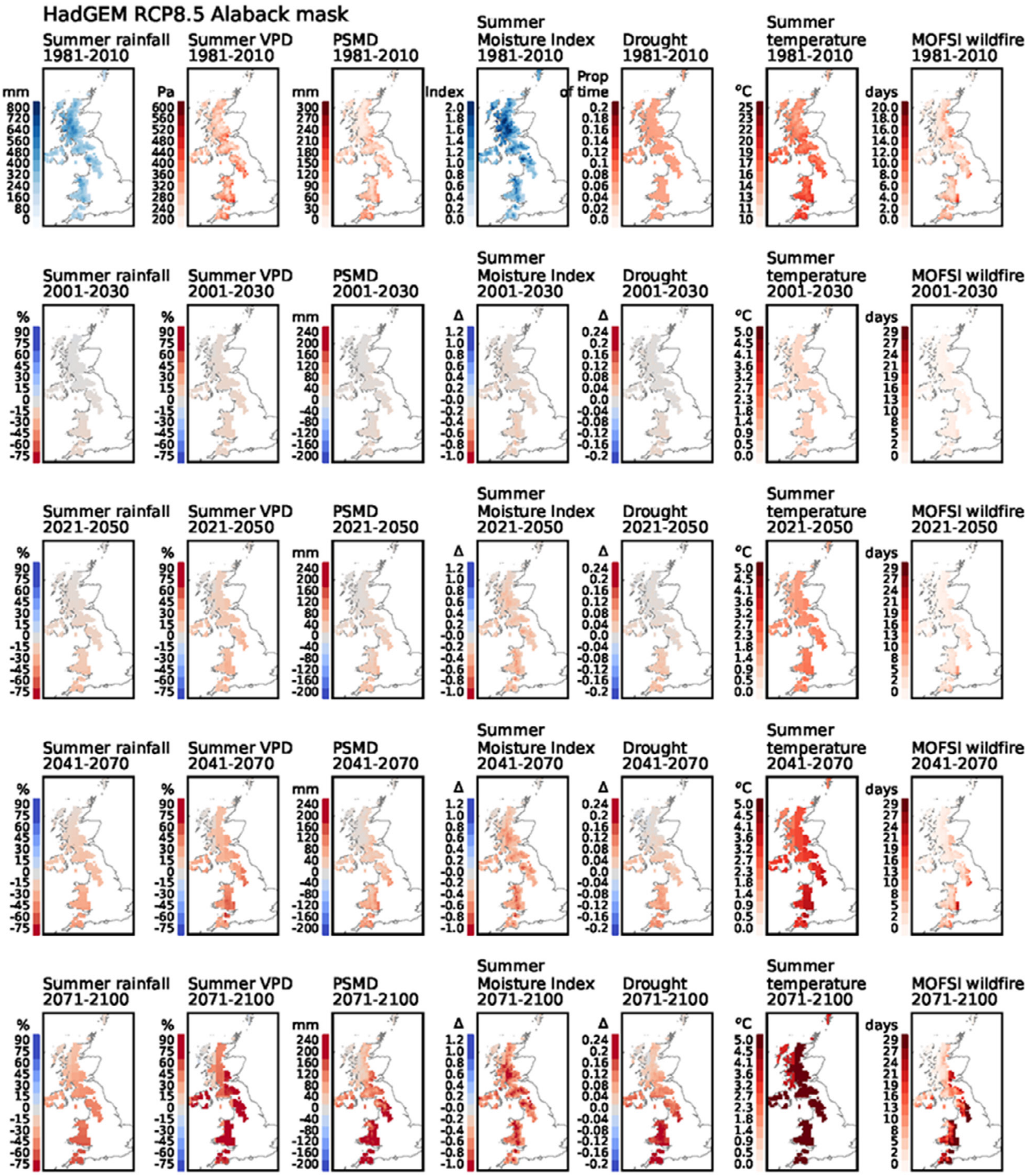

Figure 8: Change in indicators of climate relevant to temperate rainforests, with RCP8.5 very high emissions: UKCP18 HadGEM PPE-15 ensemble. The maps show the median estimate for 12x12km grid cells with at least 1km² of climate suitable for temperate rainforest under the current climate. VPD is vapour pressure deficit, PSMD is potential soil moisture deficit, and MOFSI is the Met Office Fire Severity Index.

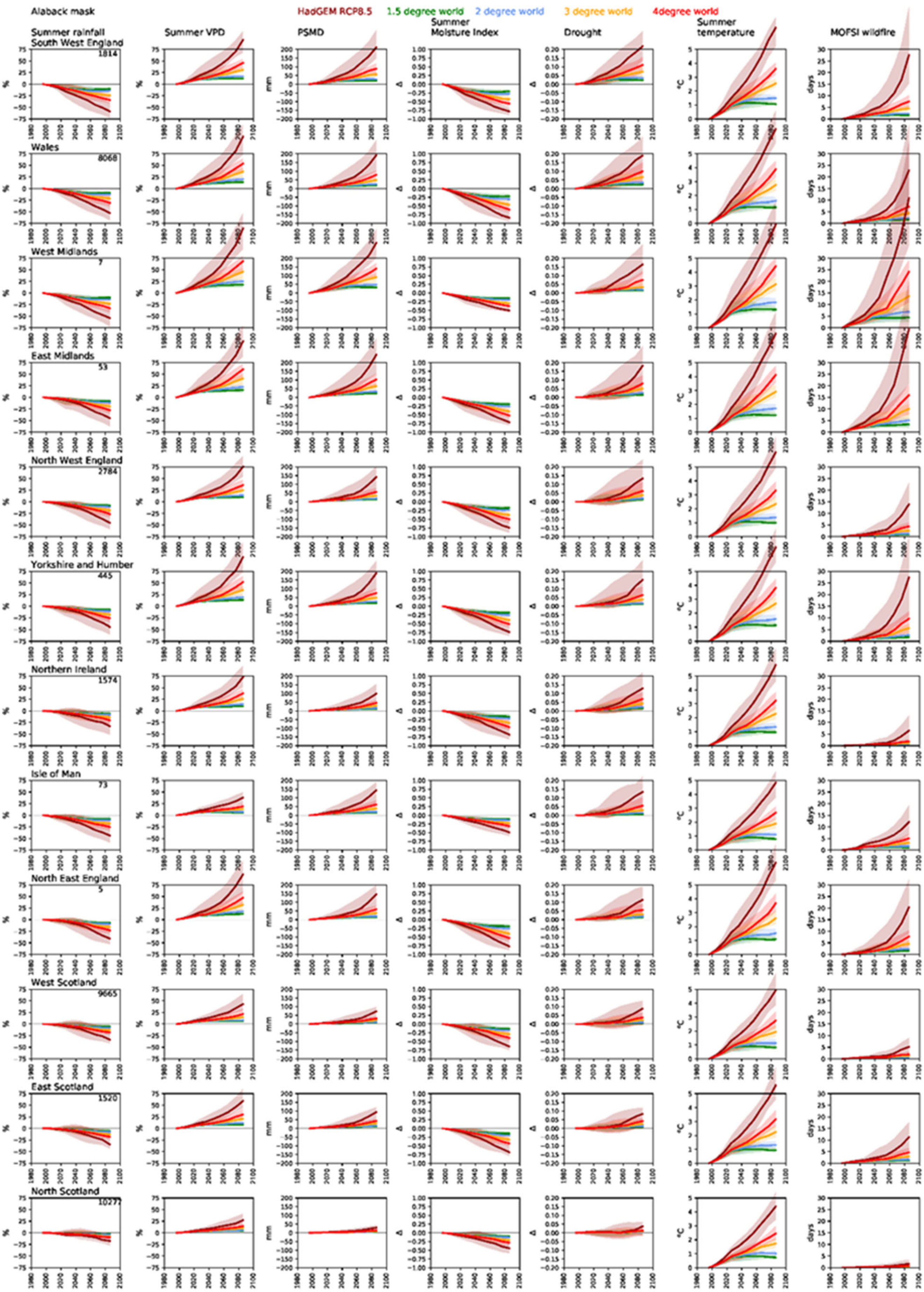

Figure 9: Regional average change over time in the indicators of climate relevant to temperate rainforests, with the five emissions pathways: UKCP18 HadGEM PPE-15 ensemble. The number in the corner of the left-hand plots shows the area. Each plot shows the median plus range across 15 ensemble members. VPD is vapour pressure deficit, PSMD is potential soil moisture deficit, and MOFSI is the Met Office Fire Severity Index.

6. Conclusions and Implications

This pilot assessment has looked at the potential effects of climate change on temperate rainforests in the UK using an indicator of climate suitability and a series of indicators of climate relevant to the sustainability of temperate rainforests. The assessment focuses on macroclimatic conditions. The characteristics of temperate rainforests in the UK are strongly influenced by microclimates, potentially varying at the scale of metres. Microclimates may be differently sensitive to changes in climate than regional and local macroclimates. They might be more vulnerable to change, or conversely less vulnerable (for example of local conditions favour continued high humidity in summer even if macroclimate changes suggest drier conditions). The pilot assessment uses a range of climate projections with different implicit or explicit levels of global warming by 2100, based on the UKCP18 HadGEM PPE-15 strand projections.

There are **three key conclusions.**

First, the key drivers of climate risk to temperate rainforests all increase, with the greatest increases in southern and western regions: conditions generally become drier and fire danger and drought risk increase. Changes in northern Scotland are relatively small even under high emissions.

Second, the risks to the viability of temperate rainforests in the UK – particularly beyond the 2050s – are strongly dependent on the pathway of future emissions. Very high emissions, as characterised by RCP8.5, would lead to extremely challenging conditions for temperate rainforests, but if the increase in global average temperature by 2100 is less than 3°C above pre-industrial levels then the risks are considerably smaller. The UKCP18 HadGEM PPE-15 projections contain larger increases in temperature for RCP8.5 than most other climate models and at the top end of the UKCP18 probabilistic range, so could be interpreted as a 'worst case' scenario.

Third, the estimated effects of climate change on the climatic suitability for temperate rainforest in the UK are very sensitive to the assumed upper summer temperature limit. With the conventionally assumed upper limit (of the average temperature of the hottest month) of 16°C, rising temperatures quickly imply that much of the UK that is currently suitable will become unsuitable. However, the evidence for this upper threshold is limited and the threshold may be higher. If so, then the suitability of the climate in the west of the UK for the development of temperate rainforest may be less sensitive to climate change than this pilot assessment suggests. The specifics of envelope-based descriptors of the climatic suitability for temperate rainforests can therefore strongly affect conclusions about their sensitivity to climate change.

This pilot assessment has identified **a number of knowledge gaps** which affect the assessment of the impacts of climate change on temperate rainforests and, by extension, the development of adaptation responses.

First, there is a need for a better understanding of where temperate rainforests can currently be found in the UK. The Lost Rainforests project provides some information, but the data base appears to include many locations which are unlikely to contain 'real' temperate rainforest based on the range of the current climate envelope. Misidentifying temperate rainforests risks misidentifying their climatic limits and therefore their sensitivity to climate change. This of course requires consistent application of a clear description of the plant and fungi assemblages characteristic of and unique to temperate rainforests (such as the lists produced by Averis, 2023).

Second, there is a need for a better understanding of the climatic limits to temperate rainforest in the UK - particularly the upper temperature threshold - and the climatic and weather conditions necessary to sustain temperate rainforest. How important, for example, are factors not included here, including the frequency of mist or fog, the number of wet days, or changes in the frequency of particular weather extremes?

Third, there is a need to examine the potential challenges to temperate rainforests from a wider range of climate scenarios. The pilot analysis here concentrates on a set of projections with a relatively large increase in temperature: would using a wider range of projections – such as more of the UKCP18 suite of projections - give a different indication of levels of risk? Are changes in relevant extremes well-represented in current climate projections? Are there any climate 'tipping points' (such as a significant weakening of the Atlantic Meridional Overturning Circulation of the Sub-Polar Gyre, or an increased frequency of cold extremes due to stronger Arctic Amplification) that would be particularly challenging to temperate rainforests?

Fourth, there is a need to develop a better understanding of how changes to climate would affect different species that make up a temperate rainforest. Would drier conditions alter characteristics completely, or simply alter species composition whilst maintaining the same general 'feel' of a temperate rainforest?

Fifth, there is a need for a more detailed assessment of the microclimates of temperate rainforests and their relationship to surrounding macroclimates. Microclimatic refugia are potentially key elements in an adaptation strategy (Ellis, 2020), and it is therefore necessary to know how changes in macroclimate will impact upon microclimates.

7. References

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