Assessing the vulnerability of blanket peat to climate change using an ensemble of statistical bioclimatic envelope models

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Climate Research 45: 131–150 (2010)

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1. EVAPOTRANSPIRATION EQUATIONS

1.1. Modified Thornthwaite Equation (Thornthwaite 1948, Mather 1978)

\[
\text{PET} = 16 \left( \frac{N}{12} \right) \left( \frac{10T_a}{\text{HI}} \right)^m
\]

(S1)

where PET is the potential evapotranspiration (mm mo⁻¹), \(T_a\) is the mean monthly temperature (°C), defined here as the mean of daily maximum and minimum temperature (Allen et al. 1998). PET was taken to be zero when \(T_a < 0\)°C. HI is the annual heat index, \(m\) is a parameter based on HI, and \(N_d\) is the mean number of daylight hours (Allen et al. 1998):

\[
\text{HI} = \sum_{i=1}^{12} \left( \frac{T_{\text{max}}}{5} \right)^{1.514}
\]

(S2)

\[
m = 6.7 \times 10^{-7} [\text{HI}]^3 - 7.7 \times 10^{-5} [\text{HI}]^2 + 1.8 \times 10^{-2} [\text{HI}] + 0.49
\]

(S3)
where \( J \) is the day of the year and \( L \) is the latitude (radians).

1.2. Priestly-Taylor Equation (Priestly & Taylor 1972)

\[
\text{PE}_0 = \alpha \left( \frac{1}{2} \right) \left( \frac{\Delta R_n - G}{\Delta + \gamma} \right)
\]

where, \( \text{PE}_0 \) is the potential evapotranspiration (mm d\(^{-1}\)), \( \alpha \) is the Priestley-Taylor coefficient (taken as 1.26 here), \( \lambda \) is the latent heat of vaporisation (2.45 MJ kg\(^{-1}\)), \( \Delta \) is the slope of the vapour pressure curve, \( \gamma \) is the psychrometric constant (kPa °C\(^{-1}\)), \( G \) is the soil heat flux (assumed to be 0 MJ m\(^{-2}\) d\(^{-1}\)), \( R_n \) is the net surface radiation (MJ m\(^{-2}\) d\(^{-1}\)). \( R_n, \Delta \), and \( \gamma \) can be calculated as (Allen et al. 1998):

\[
R_n = R_m - R_{md}
\]  
(S6)

\[
R_{ms} = (1 - A) R_a
\]  
(S7)

\[
R_a = \left( a_s + b_s \frac{n}{N} \right) R_a
\]  
(S8)

\[
R_a = \frac{24(60)}{\pi} \cdot 0.0820 \left( 1 + 0.0333 \cos \left( \frac{2\pi}{365} J \right) \right) \left[ \omega_s \sin(L) \sin(\delta) + \cos(\varphi) \cos(\delta) \sin(\omega_s) \right]
\]  
(S9)

\[
\omega_s = \arccos \left( -\tan(L) \tan(\varphi) \right)
\]  
(S10)

\[
\delta = 0.409 \sin \left( \frac{2\pi}{365} J - 1.39 \right)
\]  
(S11)

\[
R_{md} = 4.903E - 9 \left( \frac{(T_{max} + 273.3)^4 + (T_{min} + 273.3)^4}{2} \right) \left( 0.34 - 0.14 \sqrt{e_a} \right) \left[ 1.35 \frac{R_n}{R_{so}} - 0.35 \right]
\]  
(S12)

\[
e_a = 0.6108 \exp \left[ \frac{17.2T_{min}}{T_{min} + 237.3} \right]
\]  
(S13)

\[
R_{so} = (a_s + b_s) R_a
\]  
(S14)

\[
\Delta = \frac{4096 \cdot 0.6108 \exp \left( \frac{17.2T}{T + 237.3} \right)}{(T + 237.3)^2}
\]  
(S15)

\[
\gamma = \frac{c_n P}{a \lambda}
\]  
(S16)

\[
P = 101.3 \left( \frac{293 - 0.0065a}{293} \right)^{5.26}
\]  
(S17)

where \( A \) is the albedo (assumed to be 0.23), \( a_s \) and \( b_s \) are Ångström values (0.25 and 0.5, respectively), \( n \) is the actual duration of sunshine hours (hr), \( e_a \) is the actual vapour pressure (kPa) estimated from \( T_{min} \), \( T \) is the mean daily temperature (calculated from the mean of the maximum (\( T_{max} \)) and minimum daily temperature (\( T_{min} \)) °C), \( a \) is altitude (m).

1.3. Hargreaves Equation (Hargreaves et al. 1985, Allen et al. 1998)

\[
\text{PE}_0 = 0.0023(T + 17.8)(T_{max} - T_{min})^{0.5} (0.408R_a)
\]  
(S18)
2. BIOCLIMATIC ENVELOPE MODELS

Fig. S1. Classification tree of blanket peat presence (BBOG-TREE). Climate variables defined in Table 2 in the main paper. Tmax: mean maximum monthly temperature; TMI: Thornthwaite-Mather moisture index; AAMWDPT: annual accumulated monthly water deficit calculated using the Priestley-Taylor PET mode; BP: blanket peat presence (1) or absence (0). Black line: point at which the tree was stopped for the BBOG-TREE model used in the main paper.

3. ‘LD50’ FOR BLANKET PEAT BIOCLIMATIC SPACE

Table S1. ‘LD50’ for climate change required to reduce the area cover by the envelope model to 50% of the mapped area of blanket peat presence (5 km). NB: not all BCEM have 100% cover using the 1961–1990 baseline climate data.

<table>
<thead>
<tr>
<th>BCEM</th>
<th>1961–1990 blanket peat cover by BCEM</th>
<th>Precipitation change (%)</th>
<th>‘LD50’</th>
<th>Temperature change (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>GB</td>
<td>W</td>
<td>E</td>
<td>S</td>
</tr>
<tr>
<td>P50</td>
<td>67</td>
<td>82</td>
<td>52</td>
<td>69</td>
</tr>
<tr>
<td>P65-PT</td>
<td>82</td>
<td>81</td>
<td>61</td>
<td>85</td>
</tr>
<tr>
<td>LM</td>
<td>89</td>
<td>88</td>
<td>81</td>
<td>90</td>
</tr>
<tr>
<td>H-GLM</td>
<td>95</td>
<td>87</td>
<td>97</td>
<td>99</td>
</tr>
<tr>
<td>BBOG</td>
<td>95</td>
<td>91</td>
<td>95</td>
<td>97</td>
</tr>
<tr>
<td>BBOG-TREE</td>
<td>90</td>
<td>82</td>
<td>82</td>
<td>92</td>
</tr>
<tr>
<td>BBOG-GLM</td>
<td>95</td>
<td>85</td>
<td>86</td>
<td>97</td>
</tr>
<tr>
<td>BBOG-GAM</td>
<td>95</td>
<td>81</td>
<td>86</td>
<td>97</td>
</tr>
</tbody>
</table>
4. BLANKET PEAT CLIMATIC VULNERABILITY

4.1. Model threshold values

Table S2. Bioclimatic model threshold values covering certain quantiles of blanket peat distribution in Great Britain. Models are described in Table 1 in the main paper. NB: whole data set used. q = 0.001-0.05 shows blanket peat at the lower limit of the bioclimatic envelope. The table allows independent assessment of specific grid cells using the 1961–1990 baseline climate data available from http://www.metoffice.gov.uk/climatechange/science/monitoring/ukcp09/index.html

<table>
<thead>
<tr>
<th>Blanket peat cover (quantile)</th>
<th>BBOG (mm yr⁻¹)</th>
<th>BBOG-GLM</th>
<th>BBOG-GAM</th>
<th>LM-GLM</th>
<th>L-GLM</th>
<th>P(BP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;0.001</td>
<td>-73.4</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
<td>0.03</td>
<td></td>
</tr>
<tr>
<td>&lt;0.05</td>
<td>-44.9</td>
<td>0.27</td>
<td>0.27</td>
<td>0.25</td>
<td>0.23</td>
<td></td>
</tr>
<tr>
<td>&lt;0.10</td>
<td>-33.2</td>
<td>0.42</td>
<td>0.43</td>
<td>0.40</td>
<td>0.39</td>
<td></td>
</tr>
<tr>
<td>&lt;0.25</td>
<td>-15.4</td>
<td>0.65</td>
<td>0.69</td>
<td>0.62</td>
<td>0.67</td>
<td></td>
</tr>
<tr>
<td>&lt;0.50</td>
<td>0.00</td>
<td>0.87</td>
<td>0.88</td>
<td>0.87</td>
<td>0.91</td>
<td></td>
</tr>
<tr>
<td>&lt;0.75</td>
<td>0.00</td>
<td>0.97</td>
<td>0.97</td>
<td>0.99</td>
<td>0.98</td>
<td></td>
</tr>
<tr>
<td>1.00</td>
<td>0.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td></td>
</tr>
</tbody>
</table>

Blanket peat climatic vulnerability by region

Fig. S2. Blanket peat area by region based on 5 km gridded data of blanket peat presence. NB: area covering Caitheness & East Sutherland includes all RAMSAR sites (www.jncc.gov.uk)
5. BLANKET PEAT REGIONS AND SUMMARY STATISTICS

Table S3. Summary of blanket peat area and baseline climate (1961–1990) for each region shown in Fig. S2. T: mean annual temperature; Tm: maximum mean monthly temperature; T\text{max}: mean maximum monthly temperature. BBOG-TREE is described in main article and shown in Fig. S1. AW (annual wetness): areas classified by TMI; SW (seasonal wetness): areas classified by AAMWD; n/c: areas not classified with blanket peat present using BBOG-TREE.

<table>
<thead>
<tr>
<th>Country and Region</th>
<th>Area</th>
<th>Example classification (%) of mapped area</th>
<th>Climate (mean value, 1961–1990)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total 5km grid (No. cells)</td>
<td>Mapped blanket peat (km²)</td>
<td>BBOG-TREE (AW)</td>
</tr>
<tr>
<td>Scotland</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shetland</td>
<td>100</td>
<td>2500</td>
<td>648</td>
</tr>
<tr>
<td>Orkney</td>
<td>29</td>
<td>725</td>
<td>115</td>
</tr>
<tr>
<td>Caithness &amp; East Sutherland</td>
<td>216</td>
<td>5400</td>
<td>1903</td>
</tr>
<tr>
<td>Highlands</td>
<td>774</td>
<td>19350</td>
<td>3995</td>
</tr>
<tr>
<td>Western Isles</td>
<td>197</td>
<td>4925</td>
<td>1366</td>
</tr>
<tr>
<td>Grampians</td>
<td>165</td>
<td>4125</td>
<td>718</td>
</tr>
<tr>
<td>Argyle, Bute &amp; Trossachs</td>
<td>506</td>
<td>12650</td>
<td>2142</td>
</tr>
<tr>
<td>Central Belt</td>
<td>44</td>
<td>1100</td>
<td>238</td>
</tr>
<tr>
<td>Ayrshire, Dumfri &amp; Galloway</td>
<td>181</td>
<td>4525</td>
<td>1118</td>
</tr>
<tr>
<td>Scottish Borders</td>
<td>98</td>
<td>2450</td>
<td>238</td>
</tr>
<tr>
<td>England</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Northumbia</td>
<td>49</td>
<td>1225</td>
<td>325</td>
</tr>
<tr>
<td>North Pennines</td>
<td>72</td>
<td>1800</td>
<td>691</td>
</tr>
<tr>
<td>Cumbria Fells &amp; Dales</td>
<td>44</td>
<td>1100</td>
<td>182</td>
</tr>
<tr>
<td>Yorkshire Dales &amp; Bowland</td>
<td>105</td>
<td>2625</td>
<td>765</td>
</tr>
<tr>
<td>North York Moors</td>
<td>13</td>
<td>325</td>
<td>40</td>
</tr>
<tr>
<td>Peak District</td>
<td>73</td>
<td>1825</td>
<td>476</td>
</tr>
<tr>
<td>Dartmoor, Exmoor &amp; Bodmin moor</td>
<td>37</td>
<td>925</td>
<td>146</td>
</tr>
<tr>
<td>Wales</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Snowdonia &amp; North Wales</td>
<td>86</td>
<td>2150</td>
<td>393</td>
</tr>
<tr>
<td>Cambrian Mountains</td>
<td>49</td>
<td>1225</td>
<td>209</td>
</tr>
<tr>
<td>Brecon Beacons &amp; South Wales</td>
<td>30</td>
<td>750</td>
<td>52</td>
</tr>
<tr>
<td>Total</td>
<td>2868</td>
<td>71700</td>
<td>15830</td>
</tr>
</tbody>
</table>
Fig. S3. Change in bioclimatic space for (a–d) BBOG, (e–h) BBOG-TREE, (i–l) BBOG-GLM, (m–p) BBOG-GAM, under the UKCIP02 high emission scenario, for the 2020s, 2050s and 2080s.
Fig. S4. Change in bioclimatic space for (a–d) LM, (e–h) H-GLM, (i–l) P50, (m–p) P65-PT, under UKCIP02 high emission scenario, for the 2020s, 2050s and 2080s