Vulnerability of upland peatland services to climate change

Harriet Orr
Principal Scientist, Climate Change
Joanna Clark
Research Fellow, Imperial College, London
December 2009
Background

- View that blocking peat drains and gullies will ‘solve’ the problem of carbon loss/emissions and flooding
- Need for evidence of benefits of peat restoration ……
- Also, concern over ‘climate proofing’ peatland restoration

*Will money spent restoring vast areas of peatlands be worth the investment if future climate change will create unfavourable conditions for peat formation?*

Images: www.peakdistrict.org; www.moorlandassociation.org; www.moorsforthefture.org.uk
Questions from Nov07 workshop

(1) Do upland peats vary in state and change? How and why?
   (1.1) What is the condition of UK upland soils (condition maps)?
   (1.2) What are the pressures on UK upland soils (pressure maps)?

(2) What are the risks to upland soils and their services in the future?
   (2.1) What are climate and hydrogeographic conditions where peat will exist in future?
   (2.2) Can peat still form in all the uplands?
   (2.3) What are the costs and benefits of slowing peat loss in different places?
   (2.4) Where in the UK uplands can alternative land uses lead to additional C sequestration/impacts of land use change on future C storage in the uplands?

(3) What is the value of ecosystem services in uplands?
   (3.1) C storage, flood mitigation, water quality, recreation and amenity, biodiversity, etc.?
   (3.2) How does the value vary between different areas? E.g. comparison of value between pristine and degraded peat.
   (3.3) Cost benefit analysis and trade-offs

Prioritised questions

a. What are the climate and hydrogeographic conditions where peat will exist now and in future?

b. Will peat still form in the uplands in 2100?
‘Peaty’ soils are mainly in the uplands

<table>
<thead>
<tr>
<th>Soil</th>
<th>Upland</th>
<th>Lowland</th>
<th>All</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peat soils</td>
<td>11.8%</td>
<td>0.9%</td>
<td>3.0%</td>
</tr>
<tr>
<td>Blanket peat</td>
<td>11.4%</td>
<td>&lt;0.1%</td>
<td>2.2%</td>
</tr>
<tr>
<td>Raised bog</td>
<td>0.4%</td>
<td>0.2%</td>
<td>0.3%</td>
</tr>
<tr>
<td>Fen peat</td>
<td>&lt;0.1%</td>
<td>0.7%</td>
<td>0.6%</td>
</tr>
<tr>
<td>Humic rankers</td>
<td>3.7%</td>
<td>&lt;0.1%</td>
<td>0.7%</td>
</tr>
<tr>
<td>Stagnopodzols</td>
<td>11.6%</td>
<td>0.2%</td>
<td>2.4%</td>
</tr>
<tr>
<td>Stagnohumic gley soils</td>
<td>17.4%</td>
<td>0.3%</td>
<td>3.6%</td>
</tr>
<tr>
<td>Humic gley soils</td>
<td>-</td>
<td>0.3%</td>
<td>0.3%</td>
</tr>
<tr>
<td>Pelo alluvial gley soils</td>
<td>-</td>
<td>0.3%</td>
<td>0.2%</td>
</tr>
<tr>
<td><strong>All peaty soils</strong></td>
<td><strong>44.5%</strong></td>
<td><strong>2.0%</strong></td>
<td><strong>10.2%</strong></td>
</tr>
</tbody>
</table>

NB: Upland defined by SDA
What are bioclimatic envelope models?

- Bioclimatic envelope models (BCEM) are statistical models that define the ‘climate space’ occupied by subject of interest (e.g. peat).
- BCEM used to map distribution based on available climate data.

Global Boreal Peatlands
(Wieder et al., 2006)

Mire complexes in Fennoscandia
(Parvainen & Luoto, 2007)
Peat bioclimatic envelope models

Potential Distribution of boreal peatlands based on climatic data
(Wieder et al., 2006)
Assumptions/limitations

Assumes:
• current distribution of blanket peat in equilibrium with current climate
• relationship with 1961-90 climate will not change over time
• climate main driver of blanket peat -ignores other factors

Limitations
• Correlation does not necessarily mean causation
• Soil formation is slow, any changes in ‘climate space’ will alter these long term process – the peat with not disappear overnight if the envelop changes
• The main source of uncertainty in climate impact studies is the choice of GCM used – we only use one GCM here (HadCM3) from UKCIP
Bioclimatic envelope models

Published models:
• Pearsall (1950) – ‘rule of thumb’ based on precipitation > 1250 mm/yr
• Hossell et al. (2000) – logistic model based on mean temperature
• Lindsay et al. (1988) – threshold model based on raindays > 160, maximum monthly mean temperature < 15 °C, precipitation > 1000 mm/yr

Models we developed:
• Modified versions of Lindsay et al. (1988) - without raindays with GLM/GAM model fitted
• BBOG – simple threshold based on expert knowledge
• BBOG-TREE – regression tree
• BBOG-GLM – generalised linear model (logistic regression)
• BBOG-GAM – generalised additive model (cubic smoothing spline)
Derived blanket peat map

Derived map from soil survey and BGS

Presence/absence (5km gridded)
BBOG (expert based threshold)

<table>
<thead>
<tr>
<th>Climate variable</th>
<th>Units</th>
<th>95% threshold</th>
<th>No blanket peat (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Raindays</strong></td>
<td><strong>days</strong></td>
<td><strong>156</strong></td>
<td><strong>18.0</strong></td>
</tr>
<tr>
<td>Maximum temperature</td>
<td>°C</td>
<td>17.91</td>
<td>34.6</td>
</tr>
<tr>
<td>Maximum monthly mean temperature</td>
<td>°C</td>
<td>13.94</td>
<td>34.9</td>
</tr>
<tr>
<td>Potential evapotranspiration (Hargreaves)</td>
<td>mm/yr</td>
<td>589.50</td>
<td>42.6</td>
</tr>
<tr>
<td>AAMWD (Hargreaves)</td>
<td>mm/yr</td>
<td>-103.98</td>
<td>43.8</td>
</tr>
<tr>
<td><strong>AAMWD (Preistley-Taylor)</strong></td>
<td>mm/yr</td>
<td><strong>-45.14</strong></td>
<td><strong>44.1</strong></td>
</tr>
<tr>
<td>Potential evapotranspiration (Preistley-Taylor)</td>
<td>mm/yr</td>
<td>405.84</td>
<td>45.8</td>
</tr>
<tr>
<td>Thornthwaite-Mather Index</td>
<td>no units</td>
<td>0.37</td>
<td>46.7</td>
</tr>
<tr>
<td>Accumulated temperature</td>
<td>°C days</td>
<td>3150.60</td>
<td>49.8</td>
</tr>
<tr>
<td>Mean temperature</td>
<td>°C</td>
<td>8.61</td>
<td>50.0</td>
</tr>
<tr>
<td>Total precipitation</td>
<td>mm/yr</td>
<td>898.71</td>
<td>50.9</td>
</tr>
<tr>
<td>Potential evapotranspiration (Thornthwaite)</td>
<td>mm/yr</td>
<td>596.24</td>
<td>51.1</td>
</tr>
<tr>
<td>AAMWD (Thornthwaite)</td>
<td>mm/yr</td>
<td>-102.90</td>
<td>52.8</td>
</tr>
<tr>
<td>Continentality (max temp – min temp)</td>
<td>°C</td>
<td>18.63</td>
<td>55.0</td>
</tr>
<tr>
<td>Minimum temperature</td>
<td>°C</td>
<td>1.64</td>
<td>75.6</td>
</tr>
</tbody>
</table>
Threshold/GLM/GAM model structure: Modifications to Lindsay et al. (1988)
Bioclimatic envelope (1961-90) of mapped blanket peat distribution

<table>
<thead>
<tr>
<th></th>
<th>P50</th>
<th>H</th>
<th>L</th>
<th>LM</th>
<th>LM-GLM</th>
<th>LM-GAM</th>
</tr>
</thead>
<tbody>
<tr>
<td>BBOG</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BBOG-TREE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BBOG-GLM</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BBOG-GAM</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Envelope and peat
- Envelope, no peat
- Peat, no envelope
- No envelope, no peat
Sensitivity of bioclimatic envelopes to changes in climate

‘LD50’ for climate change to blanket peat bioclimatic envelope ('Lethal dose' causing 50% decline)

England: Precipitation change -2 to -41%; Temperature change +1.1 to 8.3 °C

Wales: Precipitation change -26 to -47%; Temperature change +1.3 to 12.5 °C

Scotland: Precipitation change -15 to -69%; Temperature change +2.0 to 12.0 °C
Projected changes in bioclimatic envelope: 9 model ensemble (UKCIP02)
Projected changes in bioclimatic envelope: UKCIP02 (High 2020s)
Projected changes in bioclimatic envelope: UKCIP02 (High 2050s)

<table>
<thead>
<tr>
<th></th>
<th>P50</th>
<th>H</th>
<th>LM</th>
<th>LM-GLM</th>
<th>LM-GAM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Envelope and peat</td>
<td><img src="image1" alt="Map" /></td>
<td><img src="image2" alt="Map" /></td>
<td><img src="image3" alt="Map" /></td>
<td><img src="image4" alt="Map" /></td>
<td><img src="image5" alt="Map" /></td>
</tr>
<tr>
<td>Envelope, no peat</td>
<td><img src="image6" alt="Map" /></td>
<td><img src="image7" alt="Map" /></td>
<td><img src="image8" alt="Map" /></td>
<td><img src="image9" alt="Map" /></td>
<td><img src="image10" alt="Map" /></td>
</tr>
<tr>
<td>Peat, no envelope</td>
<td><img src="image11" alt="Map" /></td>
<td><img src="image12" alt="Map" /></td>
<td><img src="image13" alt="Map" /></td>
<td><img src="image14" alt="Map" /></td>
<td><img src="image15" alt="Map" /></td>
</tr>
<tr>
<td>No envelope, no peat</td>
<td><img src="image16" alt="Map" /></td>
<td><img src="image17" alt="Map" /></td>
<td><img src="image18" alt="Map" /></td>
<td><img src="image19" alt="Map" /></td>
<td><img src="image20" alt="Map" /></td>
</tr>
</tbody>
</table>

Legend:
- Blue: Envelope and peat
- Light blue: Envelope, no peat
- Red: Peat, no envelope
- Gray: No envelope, no peat
Projected changes in bioclimatic envelope: UKCIP02 (High 2080s)

<table>
<thead>
<tr>
<th>P50</th>
<th>H</th>
<th>LM</th>
<th>LM-GLM</th>
<th>LM-GAM</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Map" /></td>
<td><img src="image2" alt="Map" /></td>
<td><img src="image3" alt="Map" /></td>
<td><img src="image4" alt="Map" /></td>
<td><img src="image5" alt="Map" /></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>BBOG</th>
<th>BBOG-TREE</th>
<th>BBOG-GLM</th>
<th>BBOG-GAM</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image6" alt="Map" /></td>
<td><img src="image7" alt="Map" /></td>
<td><img src="image8" alt="Map" /></td>
<td><img src="image9" alt="Map" /></td>
</tr>
</tbody>
</table>

Legend:
- Dark blue: Envelope and peat
- Light blue: Envelope, no peat
- Red: Peat, no envelope
- Light gray: No envelope, no peat
### Regional climate vulnerability

<table>
<thead>
<tr>
<th>Key</th>
<th>Region</th>
<th>Peat area (%)</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Northumbria</td>
<td>2.1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Dartmoor, Exmoor &amp; Bodmin Moor</td>
<td>0.9</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Peak District</td>
<td>3.0</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Brecon Beacons &amp; South Wales</td>
<td>0.3</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>North York Moors</td>
<td>0.3</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Orkney</td>
<td>0.7</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Central Belt</td>
<td>1.5</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>North Pennines</td>
<td>4.5</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>Ayrshire, Dumfris &amp; Galloway</td>
<td>4.1</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>Caithness &amp; East Sutherland</td>
<td>12.0</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Yorkshire Dales &amp; Bowland</td>
<td>4.8</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>Cambrian Mountains</td>
<td>1.3</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Scottish Boarders</td>
<td>2.0</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>Snowdonia &amp; North Wales</td>
<td>2.5</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>Grampians</td>
<td>4.5</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>Western Isles</td>
<td>8.6</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>Argyle, Bute &amp; Trossachs</td>
<td>13.5</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>Cumbria Fells &amp; Dales</td>
<td>1.2</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>Shetland</td>
<td>4.1</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td>Highlands</td>
<td>25.2</td>
<td>20</td>
</tr>
</tbody>
</table>
What are the hydrogeographic conditions for blanket peat?

- Key variables consistently selected by different models were describing cool and wet conditions:
  - Maximum temperature/max monthly mean temperature
  - Thornthwaite-Mather Index (precipitation:evaporation)
  - Annual accumulated monthly water deficit (Priestley-Taylor)

- Raindays were also an important variable, but were not included as the data is directly not available from UKCIP scenarios

- Inclusion of raindays may only make projections worse or have no change (assuming other variables selected are ‘meaningful’)
Will bioclimatic space associated with current blanket peat change by 2100?

Nine bioclimatic envelop model ensemble showed blanket peat area sensitive to climate

- LD50 temperature: +1.1 to +12.5 °C
- LD50 precipitation: -2 to -69%

UKCIP02 scenarios suggest a decline in the bioclimatic envelope associated with blanket peat:
- ‘Wet’ models show retreat to north and west
- ‘Temperature’ models show retreat to high altitude areas

Although projections vary with model, general picture shows most vulnerable areas as:
- England: Northumbria; Dartmoor/Exmoor/Bodmin; Peak District; North York Moors
- Wales: Brecon Beacons and South Wales

IMPORTANT

Bioclimatic envelope for blanket peat is not identical to the distribution of blanket peat

Blanket peat will not disappear over night!

Consider implications of change in space and transition to ‘new’ conditions e.g. vegetation change move to more ‘gley’ soil type
Do the models agree GB peat will be a source/sink in 2100?

- How reliable is the output from statistical BCEM models?
- Model comparison between statistical and dynamic models for key data rich blanket bog field sites using 11 RCMs (UKCP09)
  - Bioclimatic envelope models (*statistical relationship with climate*)
    - BBOG (Joanna Clark)
    - STASH (Angela Gallego-Sala)
  - Dynamic flux models (*source/sink calculated from net carbon fluxes*)
    - Durham Carbon model (Fred Worrall)
- Pool models
  - ECOSSE (Jo Smith/Dali Nayak)
- Peat accumulation models (*source/sink calculated from net organic matter accumulation*)
  - MILLENIA (Andreas Heinemeyer)
Model comparison (structure)

Simple statistical model based on two climatic variables ......

compared with

....... more complex dynamic process-based model (e.g. ECOSSE)
Field sites for model comparison

- **Moor House**
  - [ECN, Rob Rose, Don Monteith, Andreas Heinemeyer, Fred Worrall]

- **Conwy**
  - [Chris Evans]

- **Auchencorth Moss**
  - [CEH Edinburgh]

- **Bleaklow**
  - [Martin Evans, James Rowson, Fred Worrall]

- **BioSols (12 Sites)**
  - [Elena Vanguelova]

Images: www.fluxnet.ornl.gov; Chris Evans; Fred Worrall
Example from 11-RCM ensemble: BBOG-GLM (UKCP09 medium)

Threshold for 95% blanket peat cover 1961-90

PBP = 0.27
Summary

- Current interest in blanket bog restoration to reduce carbon losses and flood risk
- However, concern over whether peat with form in uplands under changing climate (?)
- Vulnerability maps of blanket bog to climate change will be produced using:
  - Statistical bioclimatic envelope models defining the ‘climate space’ from global and national data
  - UKCIP02/UKCP09 climate change scenarios
- Model comparison between statistical bioclimatic models and dynamic models at data rich field sites:

Do the models agree blanket bog will be a source or sink for carbon over next 100 years?
Science report

- State of knowledge of other pressures
- Stores of carbon in peat
- Wildfire
- Erosion
- Land management
- Burning
- Draining
- Grazing
- Liming and fertiliser
- Forestry
- Atmospheric deposition
- Wind farms and bio-energy
Policy briefing
What are the priorities for action now?

- Protect existing peatlands to demonstrate that we value and protect our share of global soil carbon stocks, and the other beneficial services they provide.
- Re-vegetate bare or eroding peat to minimise future vulnerability (no-regrets option)
- Monitor rates of change in carbon and GHG fluxes and vegetation to validate model projections and target areas for priority interventions
- Target monitoring of existing peat restoration work to understand impacts on runoff
- Research impacts of the shrinking bioclimatic space on runoff and flood regulation