Future scenarios for alpine ecosystems in the UK – where will we be in 50-100 years?

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Key Issues

• Multiple drivers of change;
  ➢ Climate (not just temperature; precip/snow, extremes, wind)
  ➢ N-dep and [CO$_2$]
  ➢ Grazing
  ➢ Fire

• Landscape context and complexity;
• Vulnerability vs resilience;
• Factors conferring stability.
What do we already know/understand?

- Community and landscape ecology;
  - Fraser Darling (1947), Poore & McVean (1957)

- Repeat surveying and experiments;
  - Species losses (Sydes 2008)?
  - Homogenization (Britton et al. 2009; 2017; Ross et al. 2012) - “The reduction in specialist species, homogenization of alpine heaths and declines in forb and lichen cover all represent negative changes in the biodiversity value of Scottish moorlands” (Britton et al. 2017)
Ben Macdui from Beinn Mheadhoin (20 August 2009)
A New Approach to Scottish Mountain Vegetation

Fig. 1a. Vegetation diagram – Cairngorms. Modified from Watt and Jones.
Poore & McVean (1957) J Ecol

Fig. 3. Relation of Sub-Alpine scrub to snow cover. For explanation see text.

Fig. 7. Relationship of the moss heaths to exposure on the solifluction terraces of Ruadh Stac Beag, Beinn Eighe.
Fig. 5. Stages in development of *Juncus trifidus* tussocks (a) on eroding soil where the level falls, (b) on relatively sheltered soil where gravel accumulates and the level rises. For details see text: R.I.—*Rhacomitrium lanuginosum*, L—encrusting lichens, H—hepatic crust, S—*Salix herbacea*. 
Climate drivers are modulated by landscape factors

Climate
- Temp
- Precip/snow
- Extremes

Landscape
- Heterogeneity
- History
- Geology
Beinn Heasgarnich (15 August 2015)
What do we already know/understand?

• Repeat surveying and palaeo:
  
  ➢ Grace et al. (2002) “High resolution palynological analysis at the treeline in the Cairngorms of Scotland showed a similar sluggishness [cf the Alps] over the last 1000 years (McConnell, 1996), though photographic evidence over the last 20 years suggested that trees are carrying more foliage than previously (Fig. 5)”

  ➢ “The unresponsiveness of the tree line to environmental change in the Alps and in Scotland, compared with Sweden, may reflect an increasing intensity of human activities: grazing of livestock, fire and, more recently, the increase in deer populations due to the elimination of most of their natural predators”

  ➢ In an account of the lichens of the Ben Lawers-Meall nan Tarmachan (Gilbert et al. 1988) noted the “Importance of lichen flora (431 species are accepted as having been reliably recorded from high ground of which 118 are reported for the first time.”
**Fig. 5.** Photographs of *Pinus sylvestris* at the tree line in the Cairngorms Scotland, taken from the same point in 1980 and 2000. Note the height of the crown relative to the dead main stem.
A caution about repeat surveys!

“All local plant populations must become extinct at some stage, by predation or destruction, by chance demographic events, by habitat change or, ultimately, by geological change. Searching only for known populations will inevitably suggest the resource is declining, fuelling the argument for conservation but not reflecting the true threat to the species as long as new populations are becoming established elsewhere” (Sydes 2008)
And a note about our biases

• “The lichen flora is probably the most outstanding feature of the botany of Ben Lawers; this survey confirms the international importance of the area” (Gilbert et al. 1988)

• What about endophytes and symbionts?
So what about the future?

- Multiple drivers of change;
  - Climate (not just temperature; precip, extremes, snow, wind) (Trivedi et al. 2007, 2008; Crabtree & Ellis 2010)
  - N-dep (Britton & Fisher 2007, 2008)
  - Fire (Britton & Fisher 2007)
- Landscape context and complexity (Trivedi et al. 2008; Scherrer & Körner 2011)
- Vulnerability vs resilience?
- Factors conferring stability?
Modelling warming effects ...
Table 1 – Results of generalized additive models based on occurrence data for 31 species, ordered according to magnitude of projected change in quadrat occupancy under ‘low’ and ‘high’ climate change scenarios

<table>
<thead>
<tr>
<th>Species</th>
<th>Code</th>
<th>Distributiona</th>
<th>AUCb</th>
<th>Change in occupancy (%)c</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Low</td>
</tr>
<tr>
<td>Narthecium ossifragum (L.) Huds.</td>
<td>naross</td>
<td>Oceanic Boreo-temperate</td>
<td>0.69</td>
<td>120</td>
</tr>
<tr>
<td>Dicranum scoparium</td>
<td>dicsco</td>
<td></td>
<td>0.63</td>
<td>112</td>
</tr>
<tr>
<td>Trichophorum cespitosum (L.) Hartm.</td>
<td>trices</td>
<td>Circumpolar Boreal-montane</td>
<td>0.74</td>
<td>108</td>
</tr>
<tr>
<td>Erica tetralix L.</td>
<td>eritet</td>
<td>Suboceanic temperate</td>
<td>0.67</td>
<td>93</td>
</tr>
<tr>
<td>Molinia caerulea (L.) Moench</td>
<td>molcae</td>
<td>Eurosiberian Boreo-temperate</td>
<td>0.69</td>
<td>78</td>
</tr>
<tr>
<td>Calluna vulgaris (L.) Hull</td>
<td>calvul</td>
<td>European Boreo-temperate</td>
<td>0.78</td>
<td>58</td>
</tr>
<tr>
<td>Sphagnum capillifolium</td>
<td>spcap</td>
<td></td>
<td>0.64</td>
<td>51</td>
</tr>
<tr>
<td>Enephorum vaginatum L.</td>
<td>eriavg</td>
<td>Circumpolar Boreo-Arctic montane</td>
<td>0.84</td>
<td>41</td>
</tr>
<tr>
<td>Potentilla erecta (L.) R.aeusch.</td>
<td>potere</td>
<td>Eurosiberian Boreo-temperate</td>
<td>0.74</td>
<td>31</td>
</tr>
<tr>
<td>Festuca rubra L.</td>
<td>fesrub</td>
<td>Circumpolar wide-boreal</td>
<td>0.67</td>
<td>26</td>
</tr>
<tr>
<td>Viola riviniana Rchb.</td>
<td>vioriv</td>
<td>European temperate</td>
<td>0.62</td>
<td>22</td>
</tr>
<tr>
<td>Thymus polytrichus A. Kern. Ex Borbas</td>
<td>thypol</td>
<td>European Boreo-temperate</td>
<td>0.70</td>
<td>18</td>
</tr>
<tr>
<td>Carex pulicaris L.</td>
<td>carpul</td>
<td>Suboceanic temperate</td>
<td>0.66</td>
<td>6</td>
</tr>
<tr>
<td>Juncus squarrosum L.</td>
<td>junsqu</td>
<td>Suboceanic temperate</td>
<td>0.66</td>
<td>0</td>
</tr>
<tr>
<td>Enephorum angustifolium Honck.</td>
<td>eriing</td>
<td>Circumpolar wide-boreal</td>
<td>0.68</td>
<td>0</td>
</tr>
<tr>
<td>Carex paniculata L.</td>
<td>carpan</td>
<td>European Boreo-temperate</td>
<td>0.67</td>
<td>-1</td>
</tr>
<tr>
<td>Anthoxanthum odoratum L.</td>
<td>antodo</td>
<td>Circumpolar wide-temperate</td>
<td>0.69</td>
<td>-8</td>
</tr>
<tr>
<td>Empetrum nigrum L.</td>
<td>empnig</td>
<td>Circumpolar Boreo-Arctic montane</td>
<td>0.70</td>
<td>-11</td>
</tr>
<tr>
<td>Nardus stricta</td>
<td>narstr</td>
<td>European Boreo-temperate</td>
<td>0.59</td>
<td>-20</td>
</tr>
<tr>
<td>Vaccinium vitis-idea L.</td>
<td>vacvit</td>
<td>Circumpolar Boreo-Arctic Montane</td>
<td>0.61</td>
<td>-26</td>
</tr>
<tr>
<td>Carex nigra (L.) Reichard</td>
<td>carniq</td>
<td>Eurosiberian Boreo-temperate</td>
<td>0.61</td>
<td>-40</td>
</tr>
<tr>
<td>Festuca violacea (L.) Sm.</td>
<td>fesviu</td>
<td>Circumpolar Boreo-Arctic montane</td>
<td>0.64</td>
<td>-44</td>
</tr>
<tr>
<td>Alchemilla alpina L.</td>
<td>alcap</td>
<td>European Arctic-montane</td>
<td>0.81</td>
<td>-57</td>
</tr>
<tr>
<td>Deschampsia cespitosa (L.) P. Beav.</td>
<td>desces</td>
<td>Circumpolar wide-boreal</td>
<td>0.71</td>
<td>-83</td>
</tr>
<tr>
<td>Salix herbacea L.</td>
<td>salher</td>
<td>European Arctic-montane</td>
<td>0.82</td>
<td>-85</td>
</tr>
<tr>
<td>Racomitrium lanuginosum</td>
<td>raclan</td>
<td>European Arctic-montane</td>
<td>0.75</td>
<td>-96</td>
</tr>
<tr>
<td>Carex bigelovii Torr.</td>
<td>carbig</td>
<td>Circumpolar Arctic-montane</td>
<td>0.90</td>
<td>-97</td>
</tr>
<tr>
<td>Silene acaulis (L.) Jacq.</td>
<td>silaca</td>
<td>European Arctic-montane</td>
<td>0.69</td>
<td>-100</td>
</tr>
<tr>
<td>Cladonia arbuscula</td>
<td>daarbc</td>
<td></td>
<td>0.61</td>
<td></td>
</tr>
<tr>
<td>Cladonia uncialis</td>
<td>daunc</td>
<td></td>
<td>0.69</td>
<td></td>
</tr>
<tr>
<td>Polystemium alpinum</td>
<td>polalp</td>
<td></td>
<td>0.86</td>
<td></td>
</tr>
</tbody>
</table>

a Hill et al. (1992), Preston et al. (2002).
b AUC is the Area Under the Curve of the Receiver Operating Characteristic (ROC), which is a measure of model accuracy.
c Projected change in quadrat occupancy (n = 213) is the modelled change in ‘climatic suitability’ of the quadrats.

‘Low’ = 1.7 °C
‘High’ = 3.3

Trivedi et al. (2008) Biol Conservation
Racomitrium lanuginosum / Carex bigelowii – degraded – At Meall na Samhna SAC (Stirlingshire)

Trivedi et al. (2008) suggest that this community ‘could lose suitable climate space’
Fig. 1 Strategy for comparing macro and local scale bioclimate models. Step 1 uses atlas distribution maps and bioclimatic variables for Europe to create a macro scale bioclimate model. Step 2 uses this model to predict the current species distribution across Great Britain at both 50 and 5 km grid resolutions. Step 3 compares the predicted British distribution with the observed species distribution. Step 4 is as step 2, but uses climate change scenarios to give the potential future climate space across Great Britain. Step 5 uses species records from quadrats across three nature reserves (filled triangles) in the Breadalbane mountain range (central Scottish Highlands) and fine resolution bioclimatic variables to create a local bioclimate model, which is then run under climate change scenarios. Step 6 compares the climate change projections of the macro and local models at the extent of the study site.
Fig. 3 Comparison of predicted current and projected future suitable climate space for (a) *Festuca vivipara* and (b) *Alchemilla alpina* under low and high climate change scenarios. Suitable areas are shown in red for the local models, pink for the downscaled (5 km × 5 km) models and by circles for the suitability of northern and southern 50 km grid cells of the macro model.
But is there topographic ‘buffering’, and has this been overlooked?
The potential role of topography and wind-speed ...
Ben Lawers from Ben Chonzie (18 November 2006)
Topography, aspect and snow redistribution (wind) play a role supplemental to temperature.

FIGURE 5. Snow cover duration in warm (closed circles) and cold (open circles) years from the 1959–2003 period. Dashed trend line for cold years: $r^2 = 0.94$; solid trend lines for warm years: 150–750 m, $r^2 = 0.92$; 900–1200 m, $r^2 = 0.69$. 

Trivedi et al. (2007) AAAR
Species interaction and response to wind speed alter the impact of projected temperature change in a montane ecosystem.

Fig. 3. (a) Results of hierarchical cluster analysis to identify four vegetation groups (chaining = 1.76). Groups are characterized by indicator species, with Monte Carlo tests used to estimate significance (***P < 0.001, *P < 0.01). (b) Ordination plot showing the results of partial DCA used to summarize vascular plant composition in sample plots (Δ_{axis1} = 0.436, Δ_{axis2} = 0.275). Individual transects and spatial coordinates were included as covariables, and their effects removed. Symbols are coloured according to vegetation group (cf. part a.) and size-scaled according to altitude. The vectors for vegetation parameters (canopy height and bare ground), and wind speed are derived from correlations against the axis scores.
Herbivory, and interactions with N-dep ...
Miller et al. (1999, 2010) – the role of grazing in maintaining arctic/alpine plant spp (e.g. Gentiana nivalis)

- Grazing exclosures on Ben Lawers, 1987 to 1996
- Festuca ovina-Alchemilla alpina-Silene acaulis dwarf-herb community, CG12 NVC
- Sheep maintain the plagioclimax
- Vegetation height ➔ competition
- Disturbance/bare soil ➔ recruitment
Figure 1 Conceptual model integrating impacts of nitrogen deposition and grazing. This multi-step positive feedback loop shows how atmospheric nitrogen deposition leads to the replacement of the moss *Racomitrium lanuginosum* by sedges and grasses.

van der Wal et al. (2003) *Ecology Letters*
Table 3. Climate change scenarios and possible impacts on the montane (alpine) ecosystem.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Periglacial processes</th>
<th>Soils</th>
<th>Callunetum/ Vaccinium heaths</th>
<th>Racemortium heaths</th>
<th>Juncus communities</th>
<th>Snowbed communities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Warmer, wetter winters</td>
<td>reduced frost activity</td>
<td>increased vulnerability to erosion where precipitation intensity is increased, but reduced where Racemortium expands; increased rates of pedological processes</td>
<td>expansion to higher altitudes</td>
<td>expansion to higher altitudes?</td>
<td>contraction</td>
<td>expansion or contraction depending on changes in amount or seasonal distribution of snowfall</td>
</tr>
<tr>
<td>Warmer, wetter summers</td>
<td>increased slope erosion</td>
<td>increased vulnerability to erosion</td>
<td>increased vulnerability to erosion</td>
<td>increased vulnerability to erosion</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hotter, drier summers</td>
<td>increased wind action</td>
<td>increased vulnerability to erosion</td>
<td></td>
<td>increased vulnerability to erosion possible localised contraction</td>
<td></td>
<td>possible expansion of some snowbed types</td>
</tr>
<tr>
<td>Increased precipitation intensity</td>
<td>increased slope erosion</td>
<td>increased vulnerability to erosion</td>
<td></td>
<td>increased vulnerability to erosion</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Increased wind speeds</td>
<td>increased erosion</td>
<td>increased vulnerability to erosion if plant cover</td>
<td></td>
<td>increased vulnerability to Racemortium</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Conclusions

• We’re doomed?
• Smaller and increasingly isolated habitat
• Is environmental heterogeneity sufficient to buffer populations against change?
• Do we know enough about physiological tolerances?
• Do we know enough about reproductive performance/success and dispersal?
• Grazing management will be essential
• What about symbionts? Other trophic/species interactions
Literature cited

The Scottish montane

- Montane habitats in Scotland are some of the least affected by direct human activity in the UK;
- But grazing pressure is high (32% increase in sheep density between 1950-1990; doubling of red deer population between 1959-1989, allegedly!);
- Large mammalian predators extinct;
- Acidifying pollutant deposition is high (well in excess of critical loads);
- The prognoses for doubling CO$_2$: \[ \rightarrow 200-960 \text{ m upwards} \]
  \[ \rightarrow 93\% \text{ reduction in arctic-alpine habitat in Scotland (Scottish Biodiversity Forum 2003)} \]
- Montane systems not included in the UKBAP ‘Priority Habitats’!
- Aesthetics and cultural identity are important.
Exceedance of acidity and nutrient N using deposition data for 2002-04 (using 1km 5th percentile critical loads)

Source: CEH and DEFRA; http://www.ceh.ac.uk/sections/er/Critical_loads.htm
Figure N2: Habitat area (by type) in which critical load for nitrogen was exceeded during four time periods*

Source: CEH published and unpublished data

*2004 total mapped habitat area is shown to provide context. The percentage of the area exceeded is highlighted for the most and least recent time period.

Source: SEPA 2006
Implications of loss of willow?

• Associated species (e.g. nesting birds, under-storey plant species)?

• Changes in water balance (interception; transpiration; surface run-off; erosion; water chemistry)?

• Links with grazers (top-down control by sheep and deer, or bottom-up control by plant chemistry?);

• In Norway, migration of willow scrub up-slope is considered a threat to mid-alpine systems!