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

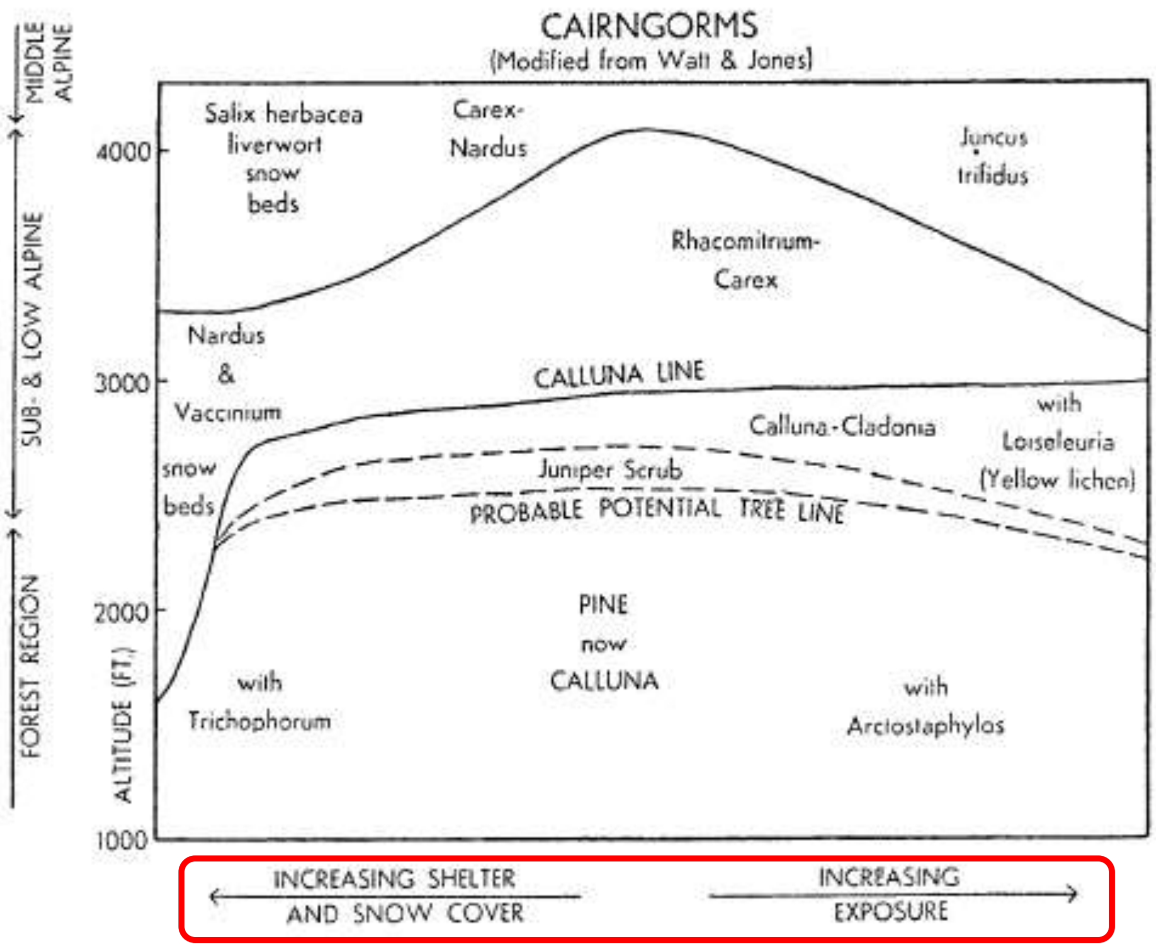


Fig. 1a. Vegetation diagram – Cairngorms. Modified from Watt and Jones.

Poore & McVean (1957) J Ecol

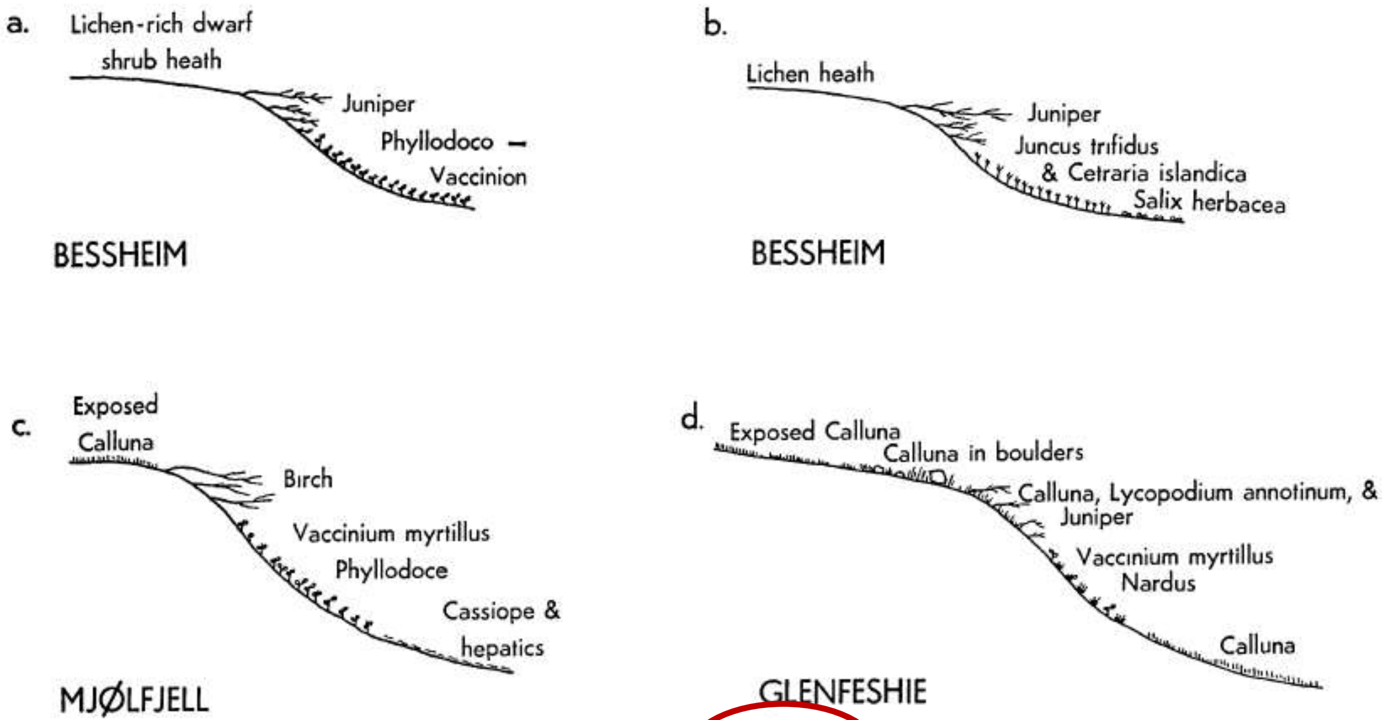


Fig. 3. Relation of Sub-Alpine scrub to snow cover. For explanation see text.

Poore & McVean (1957) J Ecol

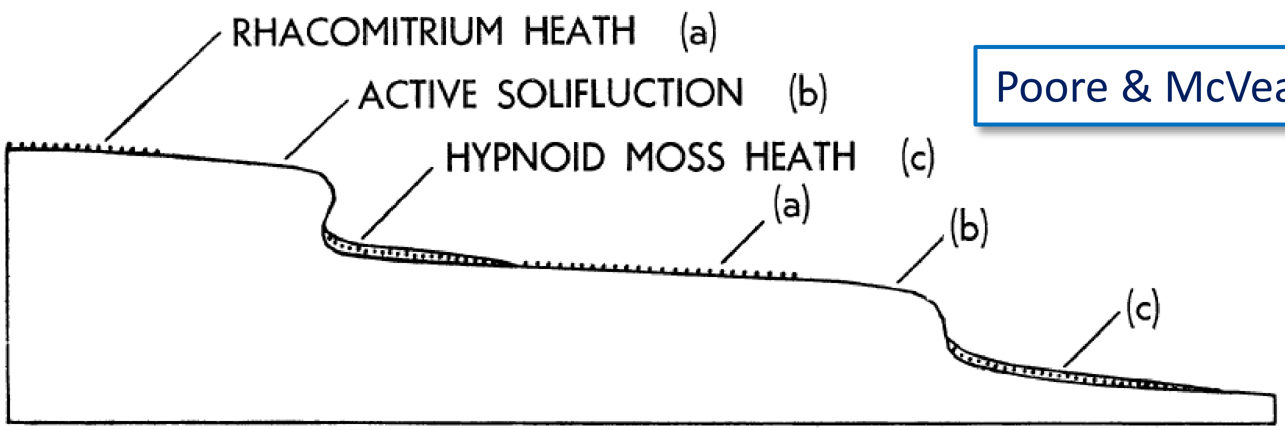


Fig. 7. Relationship of the moss heaths to exposure on the solifluction terraces of Ruadh Stac Beag, Beinn Eighe.

Ciste Mhearad (20 August 2009)


Stob Poite Coire Ardair (4 October 2009)

Ingram (1958) *J Ecol*

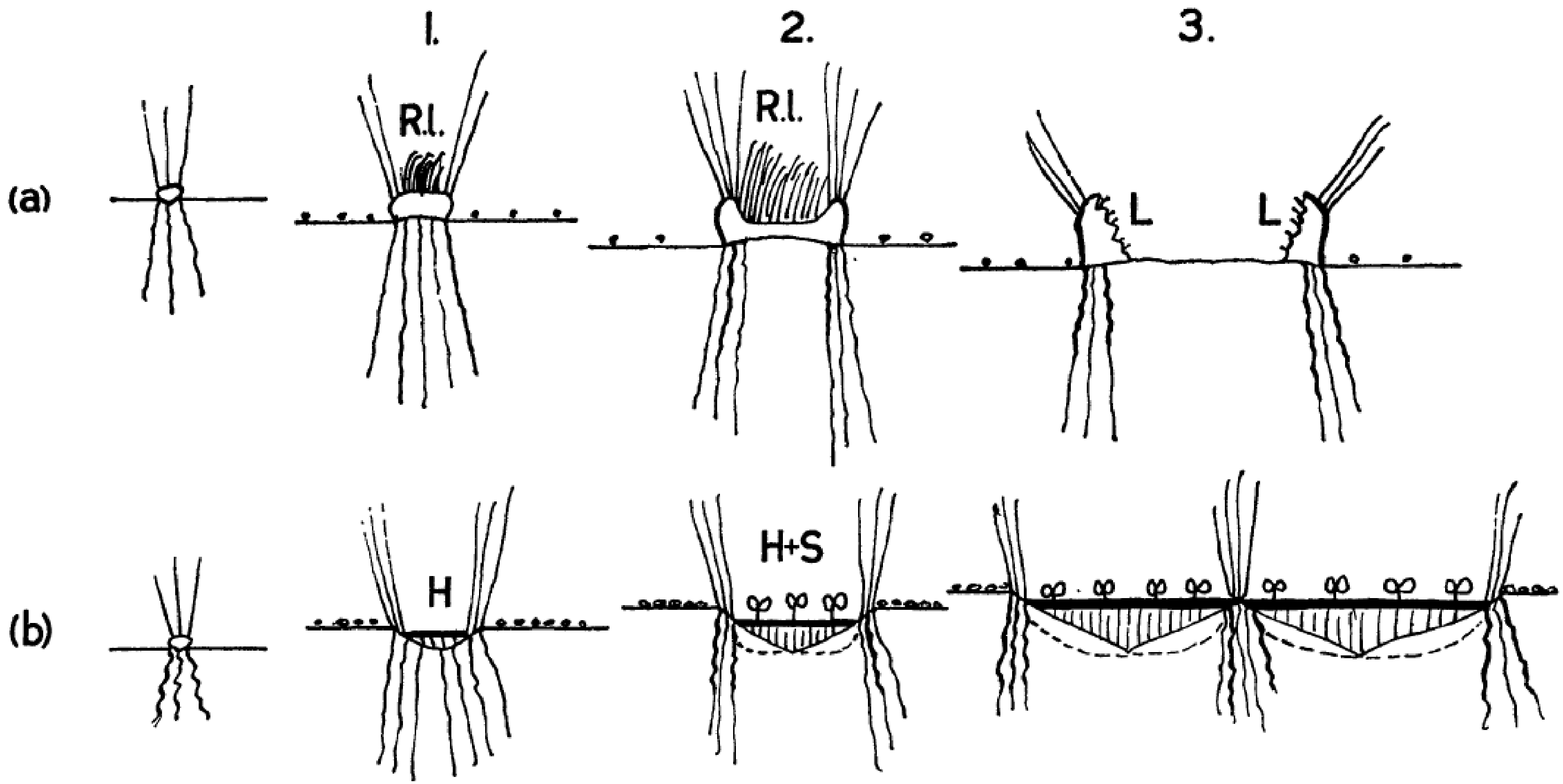


Fig. 5. Stages in development of *Juncus trifidus* tussocks (*a*) on eroding soil where the level falls, (*b*) on relatively sheltered soil where gravel accumulates and the level rises. For details see text: R.l.—*Rhacomitrium lanuginosum*, L—encrusting lichens, H—hepatic crust, S—*Salix herbacea*.

Climate drivers are modulated by landscape factors

Climate

- Temp
- Precip/snow
- Extremes

Landscape

- Heterogeneity
- History
- Geology

Beinn Heasgarnich (15 August 2015)

Beinn Heasgarnich (15 August 2015)


Creag Meagaidh (7 October 2007)

Creag Meagaidh (7 October 2007)


Creag Meagaidh (7 October 2007)

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."

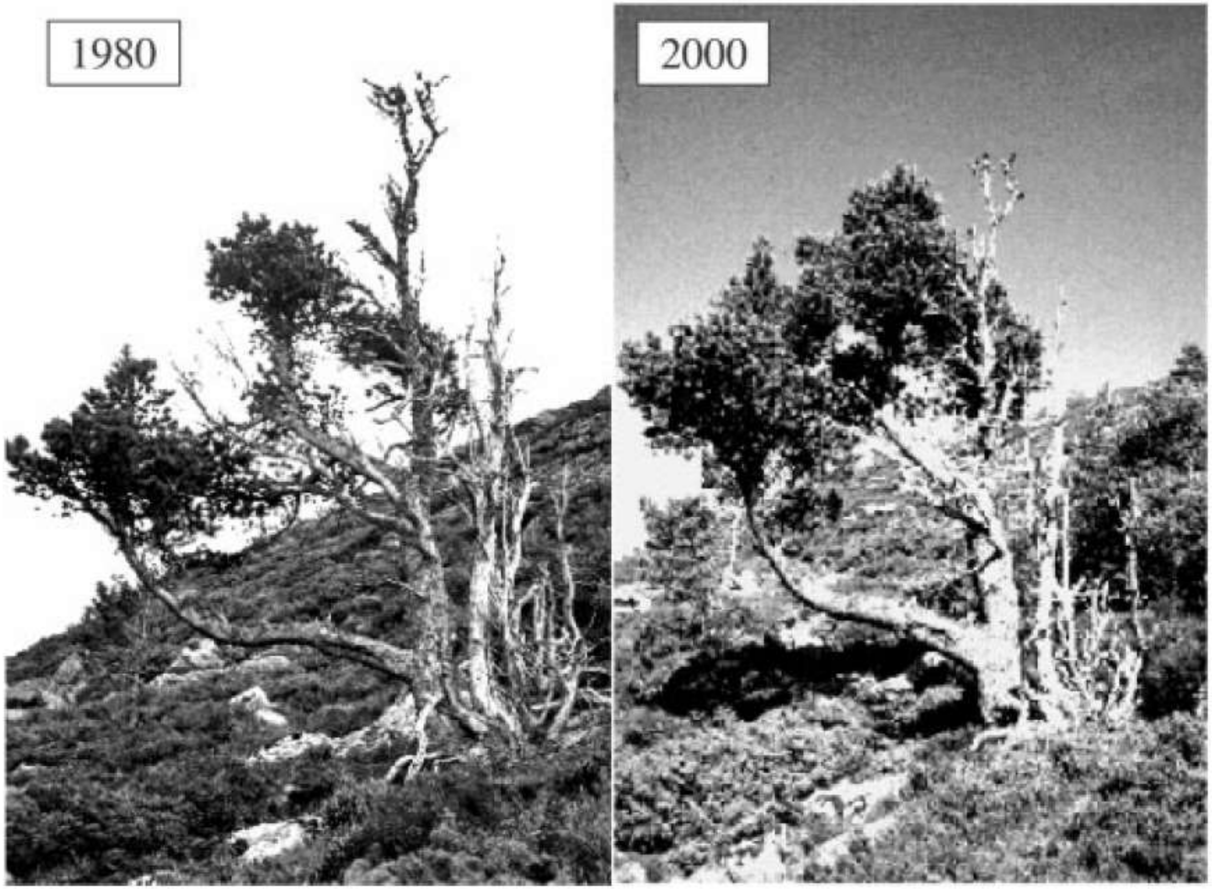


FIG. 5. Photographs of *Pinus sylvestris* at the tree line in the Cairngorms Scotland, taken from the same point in 1980 and 2000. Note the height of the crown relative to the dead main stem.

Grace *et al.* (2002) Annals of Botany

A caution about repeat surveys!

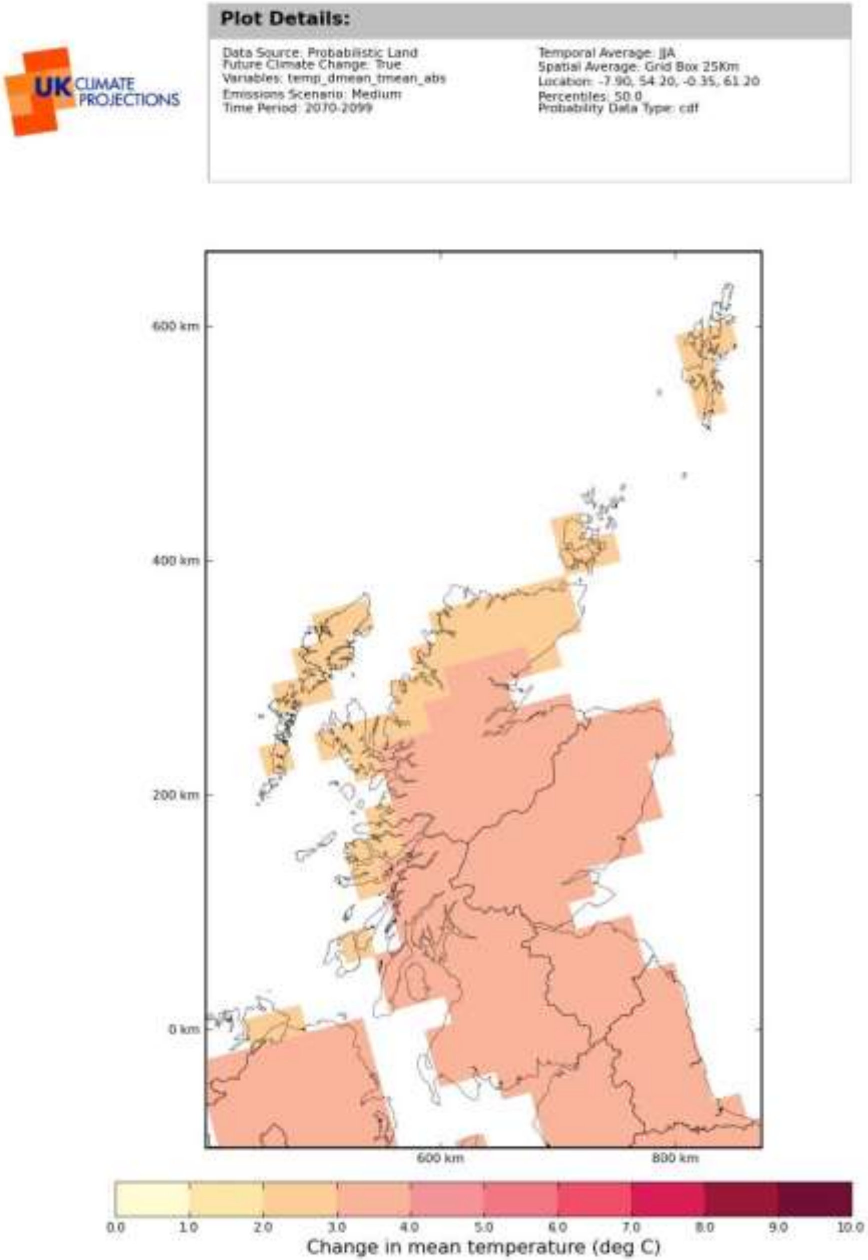
- “All local plant populations must become extinct at some stage, by predation or destruction, by chance demographic events, by habitat change or, ultimately, by geological change. Searching only for known populations will inevitably suggest the resource is declining, fuelling the argument for conservation 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 out-standing 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)
  - ➢ Grazing (Britton *et al.* 2007, 2009, 2017; Miller *et al.* 1999, 2010)
  - ➢ Fire (Britton & Fisher 2007)
- Landscape context and complexity (Trivedi *et al.* 2008; Scherrer & Körner 2011)
- Vulnerability vs resilience?
- Factors conferring stability?



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Spatial Average: Grid Box 25Km
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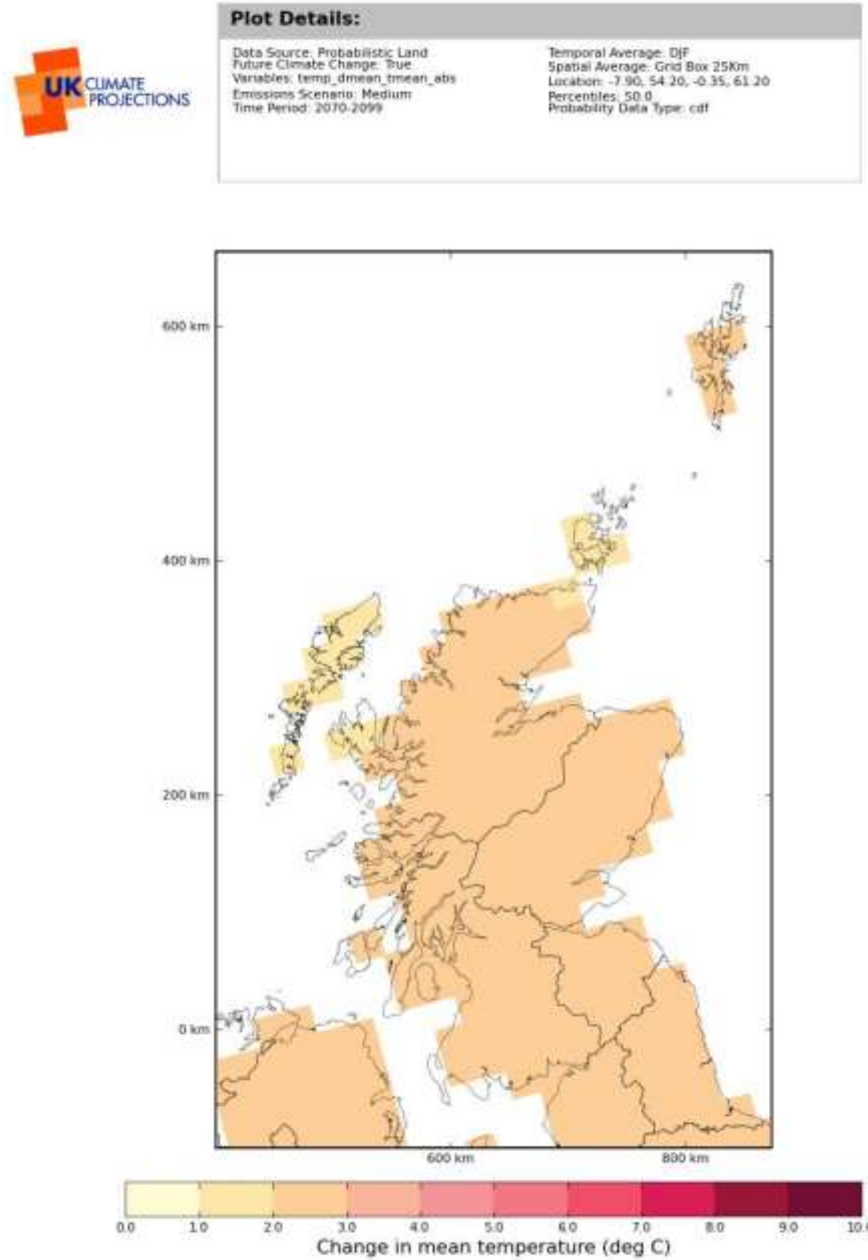
Percentiles: 50.0
Probability Data Type: cdf
600 km
400 km
200 km
0 km
600 km
800 km
0.0 1.0 2.0 3.0 4.0 5.0 6.0 7.0 8.0 9.0 10.0
Change in mean temperature (deg C)



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Location: -7.90, 54.20, -0.35, 61.20
Percentiles: 50.0
Probability Data Type: cdf
600 km
400 km
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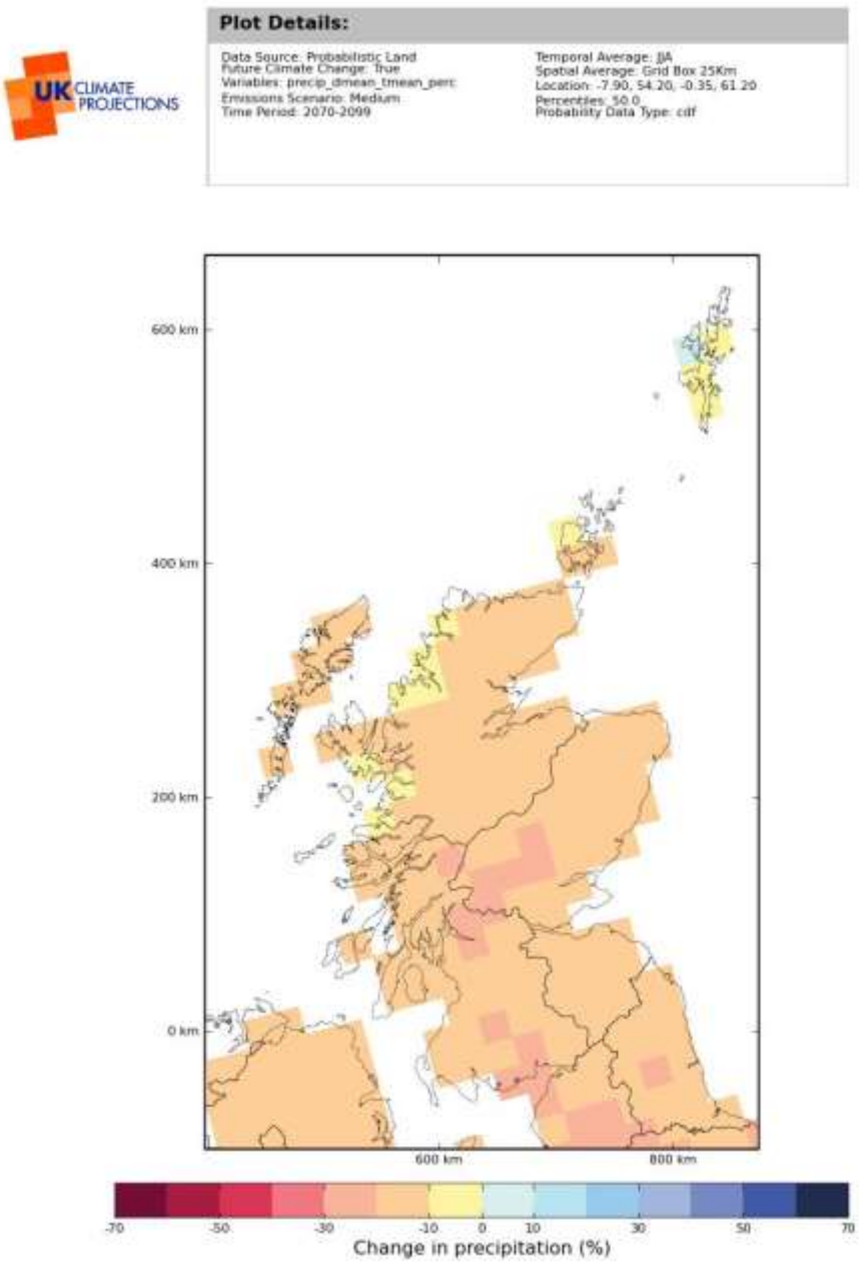
0.0 1.0 2.0 3.0 4.0 5.0 6.0 7.0 8.0 9.0 10.0
Change in mean temperature (deg C)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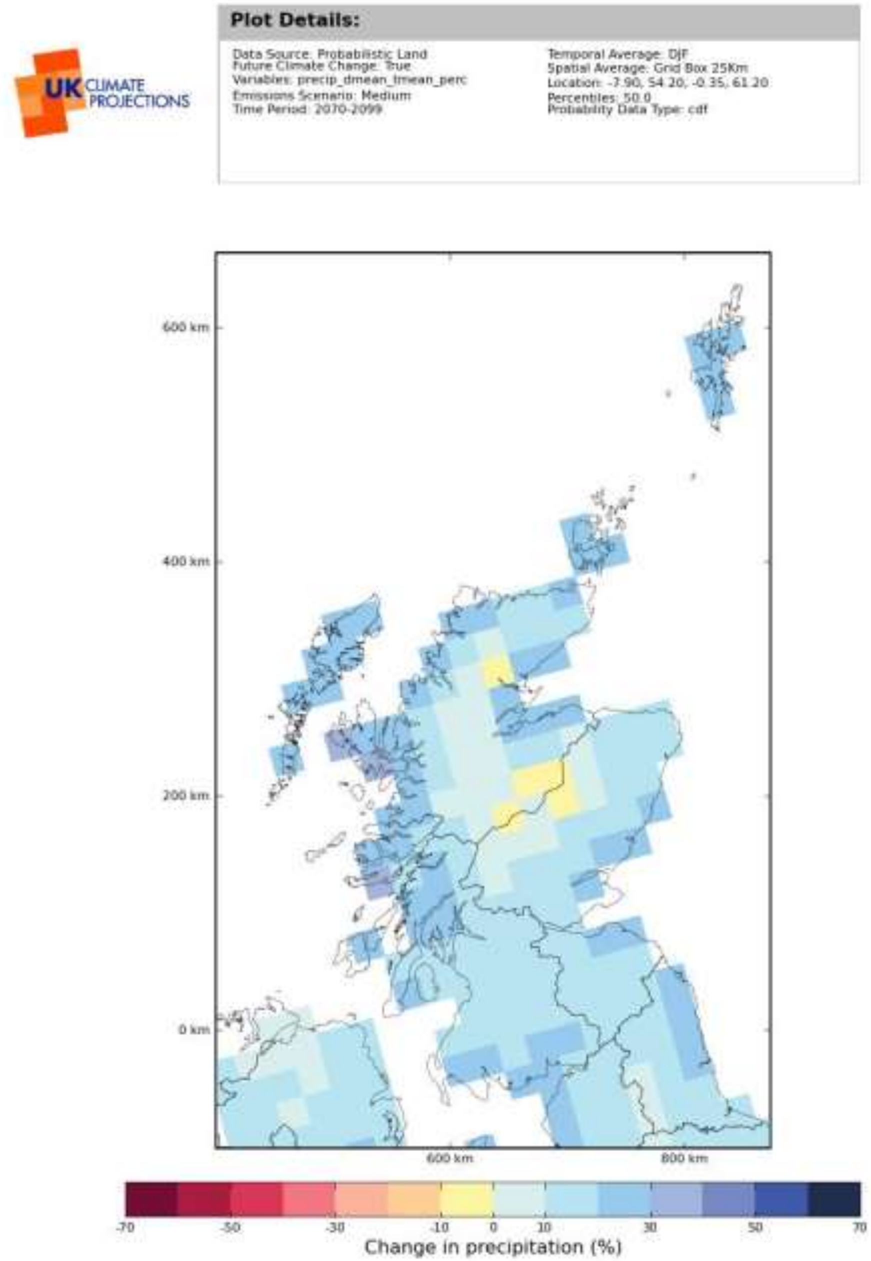
Temporal Average: JJA
Spatial Average: Grid Box 25Km
Location: -7.90, 54.20, -0.35, 61.20
Percentiles: 50.0
Probability Data Type: cdf
600 km
400 km
200 km
0 km
600 km
800 km
-70
-50
-30
-10
0
10
30
50
70
Change in precipitation (%)


UK CLIMATE PROJECTIONS
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Temporal Average: DJF
Spatial Average: Grid Box 25Km
Location: -7.90, 54.20, -0.35, 61.20
Percentiles: 50.0
Probability Data Type: cdf
600 km
400 km
200 km
0 km
600 km
800 km
-70
-50
-30
-10
0
10
30
50
70
Change in precipitation (%)

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

Species	Code	Distribution[a]	AUC[b]	Change in occupancy (%)[c]	
				Low	High
Narthecium ossifragum (L.) Huds.	naross	Oceanic Boreo-temperate	0.69	120	178
Dicranum scoparium	dicsco		0.63	112	265
Tricophorum cespitosum (L.) Hartm.	trices	Circumpolar Boreal-montane	0.74	108	176
Erica tetralix L.	eritet	Suboceanic temperate	0.67	93	166
Molinia caerulea (L.) Moench	molcae	Eurosiberian Boreo-temperate	0.69	78	230
Calluna vulgaris (L.) Hull	calvul	European Boreo-temperate	0.78	58	111
Sphagnum capillifolium	sphcap		0.64	51	95
Eriophorum vaginatum L.	erivag	Circumpolar Boreo-Arctic montane	0.84	41	114
Potentilla erecta (L.) Raeusch.	potere	Eurosiberian Boreo-temperate	0.74	31	58
Festuca rubra L.	fesrub	Circumpolar wide-boreal	0.67	26	21
Viola riviniana Rchb.	vioriv	European temperate	0.62	22	0
Thymus polytrichus A. Kern. Ex Borbas	thypol	European Boreo-temperate	0.70	18	8
Carex pulicaris L.	carpul	Suboceanic temperate	0.66	17	−59
Juncus squarrosus L.	junsqu	Suboceanic temperate	0.66	6	−7
Eriophorum angustifolium Honck.	eriang	Circumpolar wide-boreal	0.68	0	−2
Carex paniculata L.	carpan	European Boreo-temperate	0.67	0	−47
Anthoxanthum odoratum L.	antodo	Circumpolar wide-temperate	0.69	−1	−24
Empetrum nigrum L.	empnig	Circumpolar Boreo-Arctic montane	0.70	−8	4
Nardus stricta	narstr	European Boreo-temperate	0.59	−11	−41
Vaccinium vitis-idaea L.	vacvit	Circumpolar Boreo-Arctic Montane	0.61	−20	−40
Carex nigra (L.) Reichard	carnig	Eurosiberian Boreo-temperate	0.61	−26	−64
Festuca vivipara (L.) Sm.	fesviv	Circumpolar Boreo-Arctic montane	0.64	−40	−74
Alchemilla alpina L.	alcalp	European Arctic-montane	0.81	−44	−74
Deschampsia cespitosa (L.) P. Beauv.	desces	Circumpolar Wide-boreal	0.71	−57	−81
Salix herbacea L.	salher	European Arctic-montane	0.82	−83	−100
Racomitrium lanuginosum	raclan		0.75	−85	−100
Carex bigelowii Torr.	carbig	Circumpolar Arctic-montane	0.90	−88	−98
Silene acaulis (L.) Jacq.	silaca	European Arctic-montane	0.69	−89	−100
Cladonia arbuscula	claarb		0.61	−96	−100
Cladonia uncialis	claunc		0.69	−97	−100
Polytrichum alpinum	polalp		0.86	−100	−100

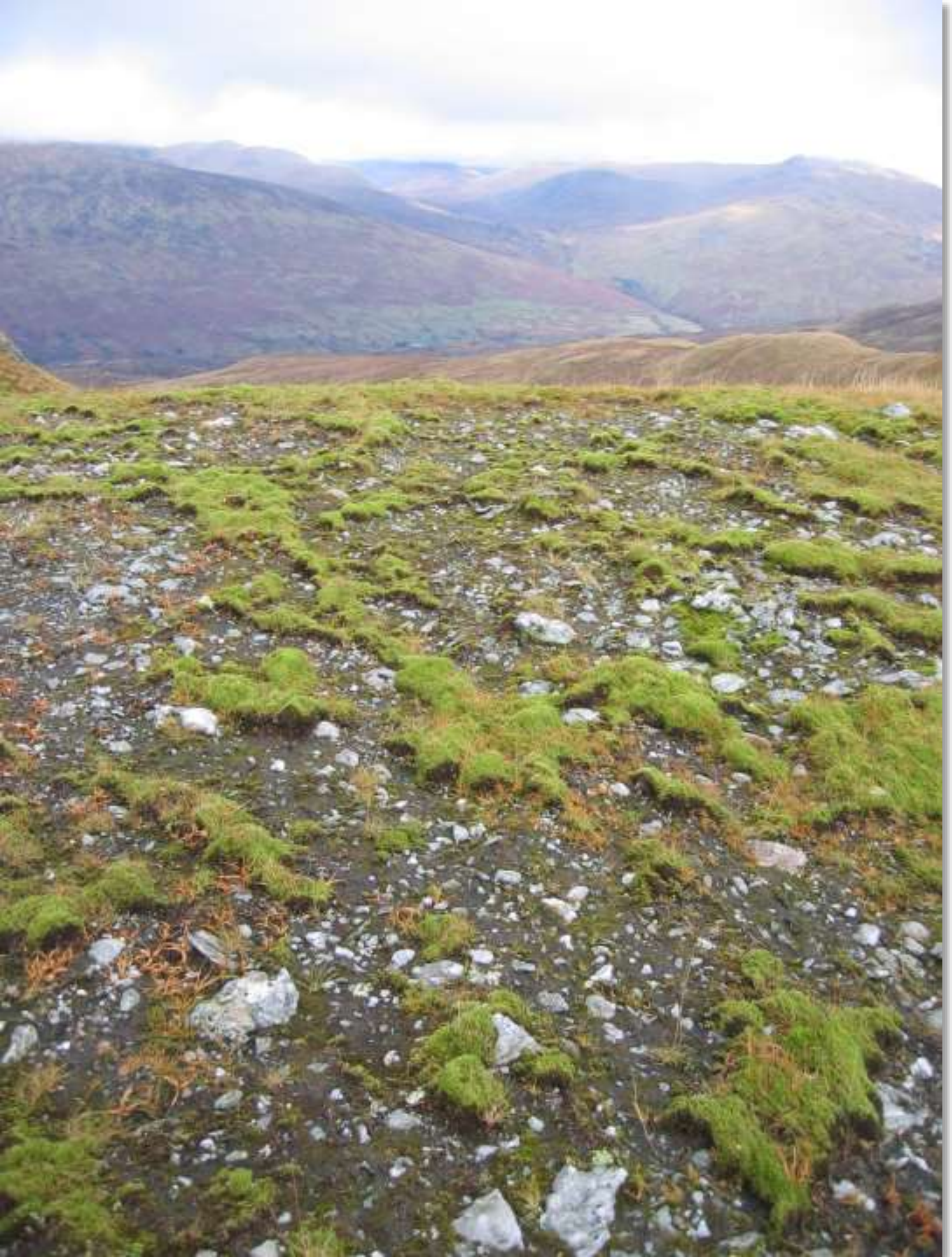
a Hill et al. (1992), Preston et al. (2002).

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'

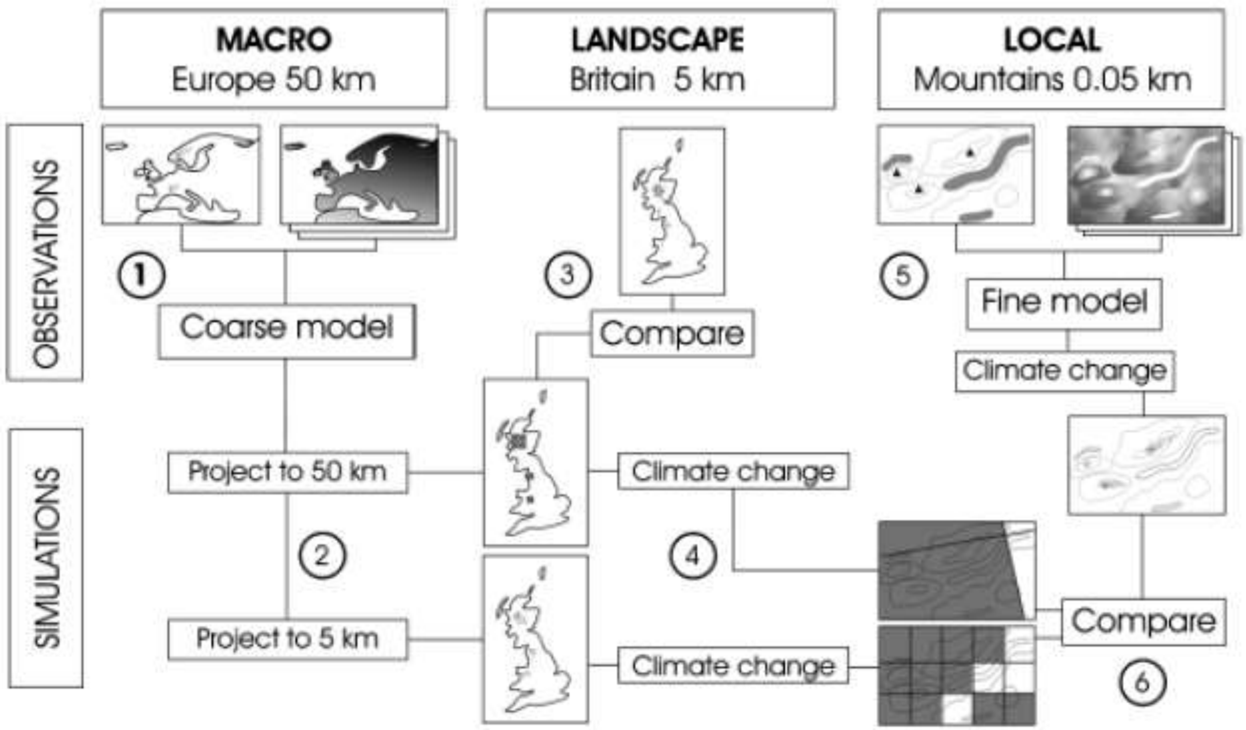


Fig. 1 Strategy for comparing macro and local scale bioclimate models. *Step 1* uses atlas distribution maps and bioclimatic variables for Europe to create a macro scale bioclimate model. *Step 2* uses this model to predict the current species distribution across Great Britain at both 50 and 5 km grid 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.

Trivedi *et al.* (2008) GCB

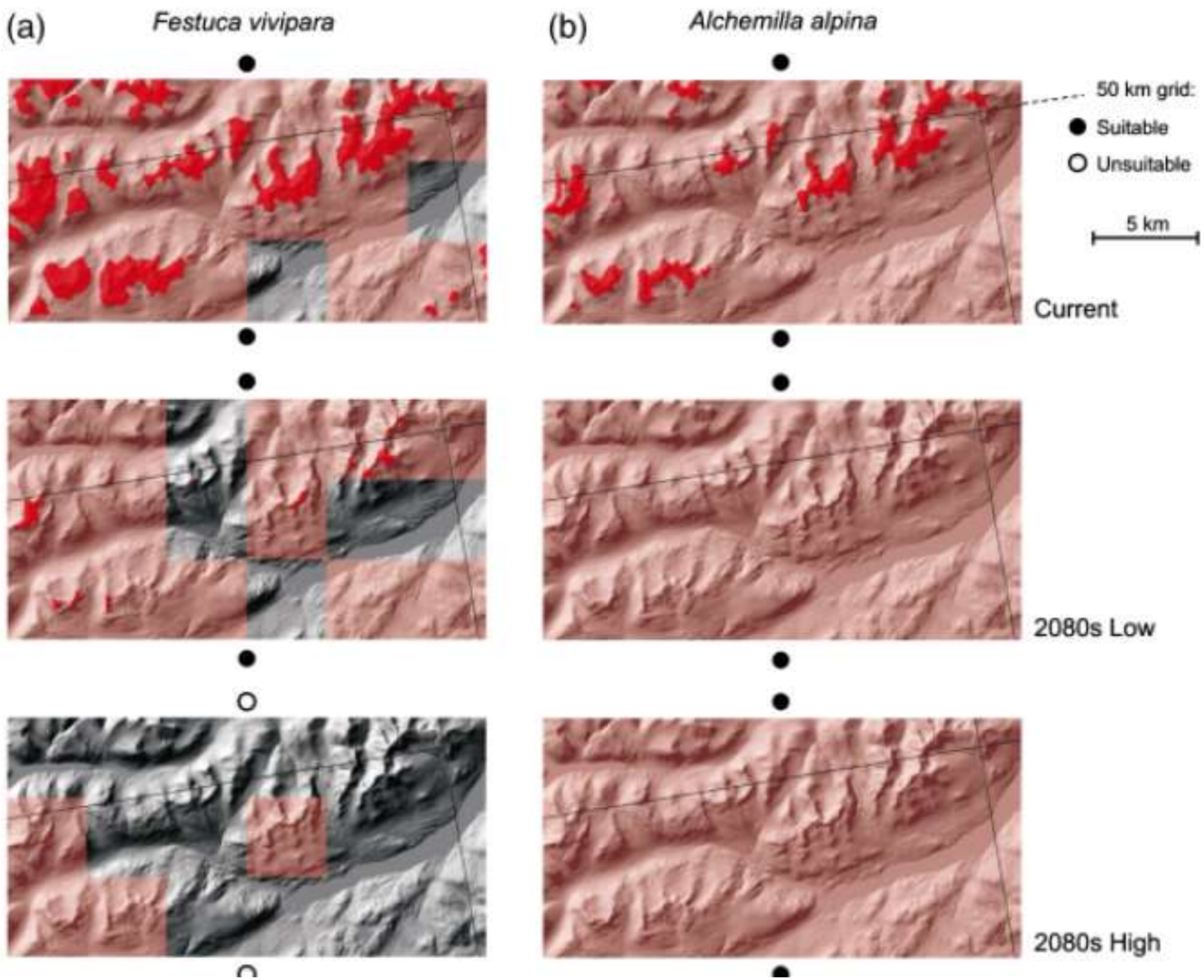


Fig. 3 Comparison of predicted current and projected future suitable climate space for (a) *Festuca vivipara* and (b) *Alchemilla alpina* under low and high climate change scenarios. Suitable areas are shown in red for the local models, pink for the downscaled (5 km × 5 km) models and by circles for the suitability of northern and southern 50 km grid cells of the macro model.

Trivedi *et al.* (2008) GCB

But is there topographic ‘buffering’, and has this been overlooked?

Journal of Biogeography (*J. Biogeogr.*) (2011) **38**, 406–416

ORIGINAL ARTICLE

Topographically controlled thermal-habitat differentiation buffers alpine plant diversity against climate warming

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ABSTRACT

Aim We aim to: (1) explore thermal habitat preferences in alpine plant species across mosaics of topographically controlled micro-habitats; (2) test the predictive value of so-called ‘indicator values’; and (3) quantify the shift in micro-habitat conditions under the influence of climate warming.

Location Alpine vegetation 2200–2800 m a.s.l., Swiss central Alps.

Methods High-resolution infra-red thermometry and large numbers of small data loggers were used to assess the spatial and temporal variation of plant-surface and ground temperatures as well as snow-melt patterns for 889 plots distributed across three alpine slopes of contrasting exposure. These environmental data were then correlated with Landolt indicator values for temperature preferences of different plant species and vegetation units. By simulating a uniform 2 K warming we estimated the changes in abundance of micro-habitat temperatures within the study area.

The potential role of topography and wind-speed …

Ben Lawers from Ben Chonzie (18 November 2006)

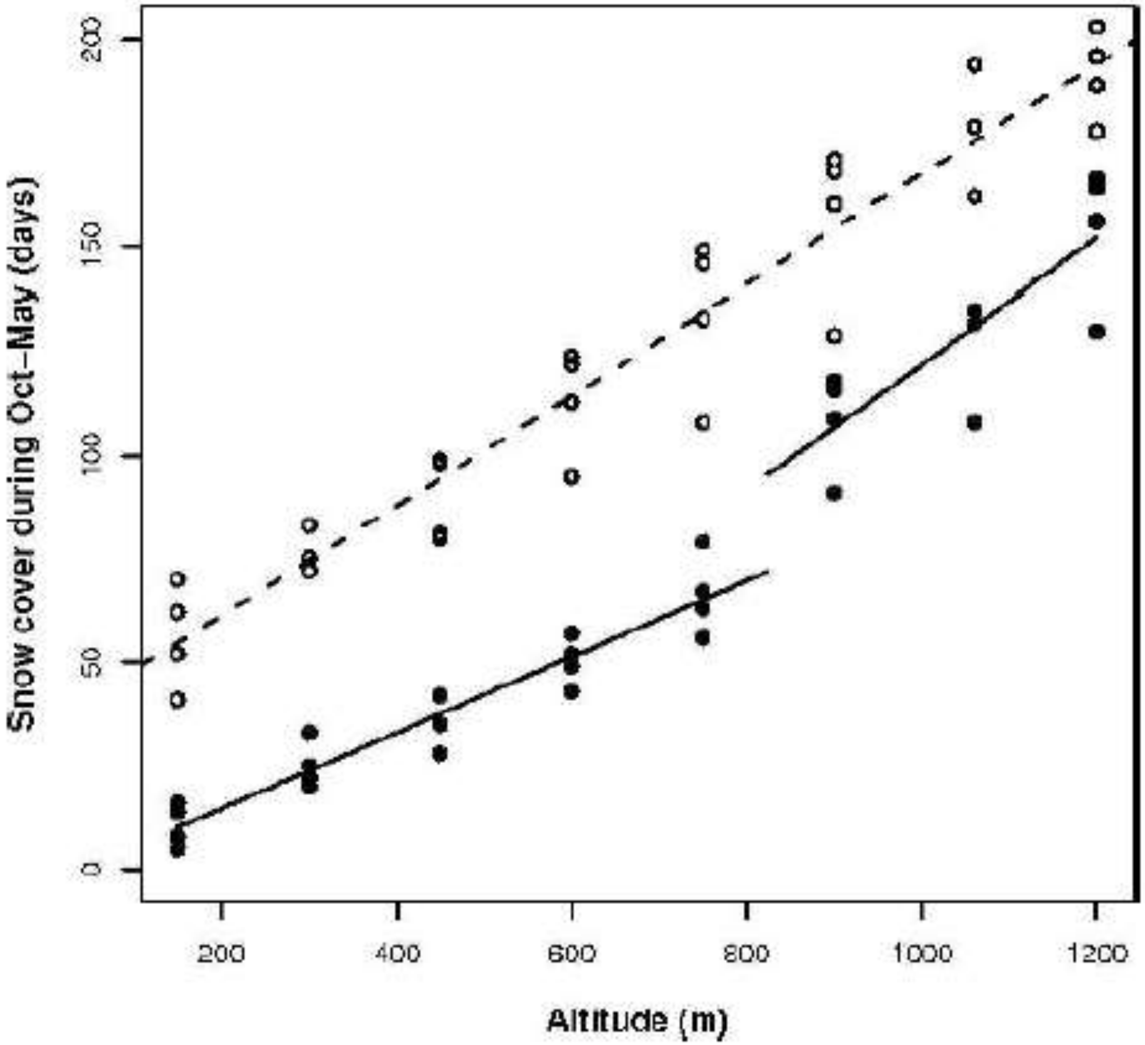

FIGURE 5. Snow cover duration in warm (closed circles) and cold (open circles) years from the 1959–2003 period. Dashed trend line for cold years: $r^2 = 0.94$; solid trend lines for warm years: 150–750 m, $r^2 = 0.92$; 900–1200 m, $r^2 = 0.69$.

Topography, aspect and snow redistribution (wind) play a role supplemental to temperature.

Trivedi *et al.* (2007) AAAR

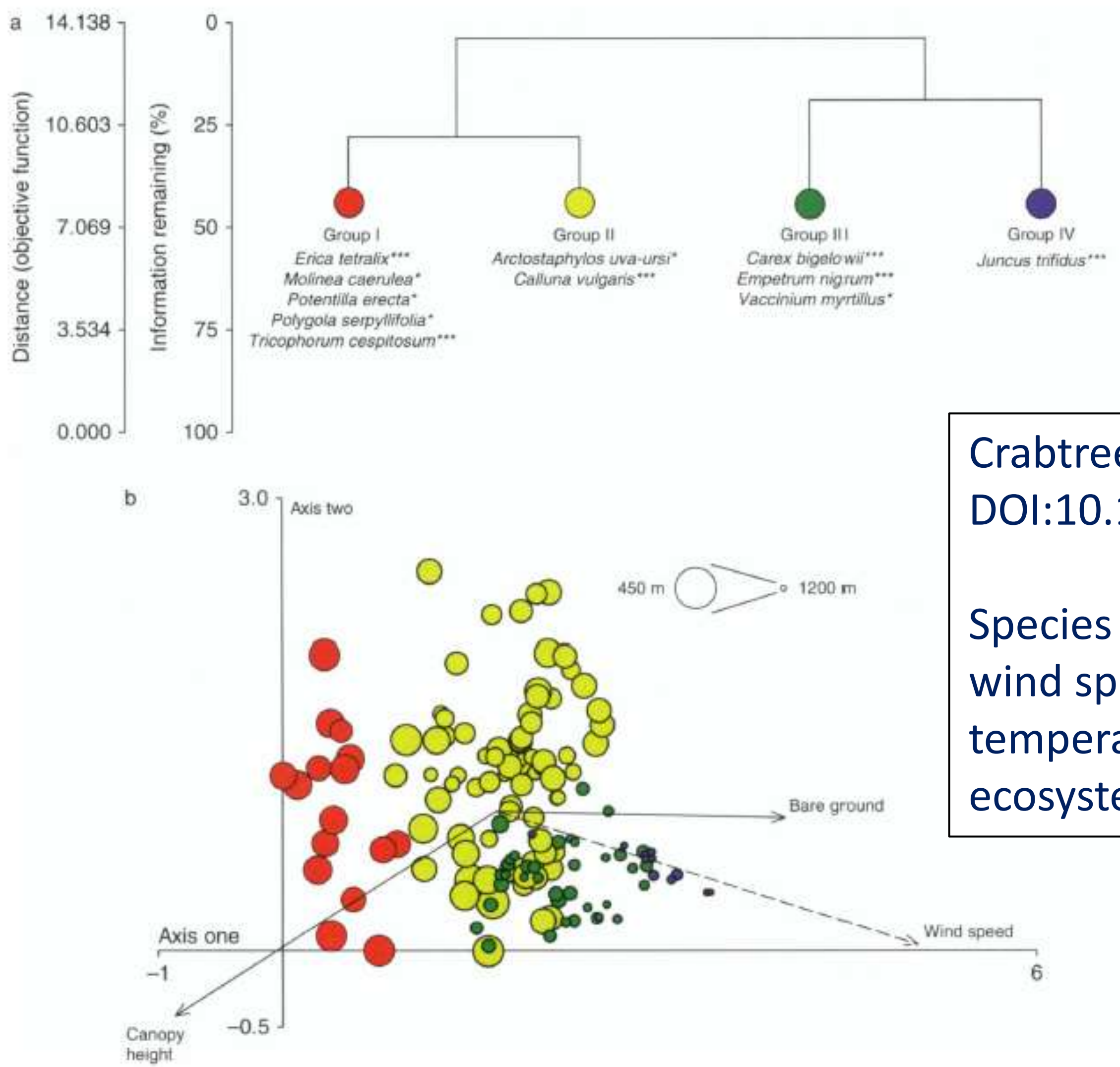

Fig. 3. (a) Results of hierarchical cluster analysis to identify four vegetation groups (chaining = 1.76). Groups are characterized by indicator species, with Monte Carlo tests used to estimate significance (***$P < 0.001$, *$P < 0.01$). (b) Ordination plot showing the results of partial DCA used to summarize vascular plant composition in sample plots ($\Delta_{axis1} = 0.436$, $\Delta_{axis2} = 0.275$). 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.

Crabtree & Ellis (2010) JVS
DOI:10.1111/j.l654-1103.2010.01184.x

Species interaction and response to wind speed alter the impact of projected temperature change in a montane ecosystem

Beinn Mheadhoin (20 August 2009)

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

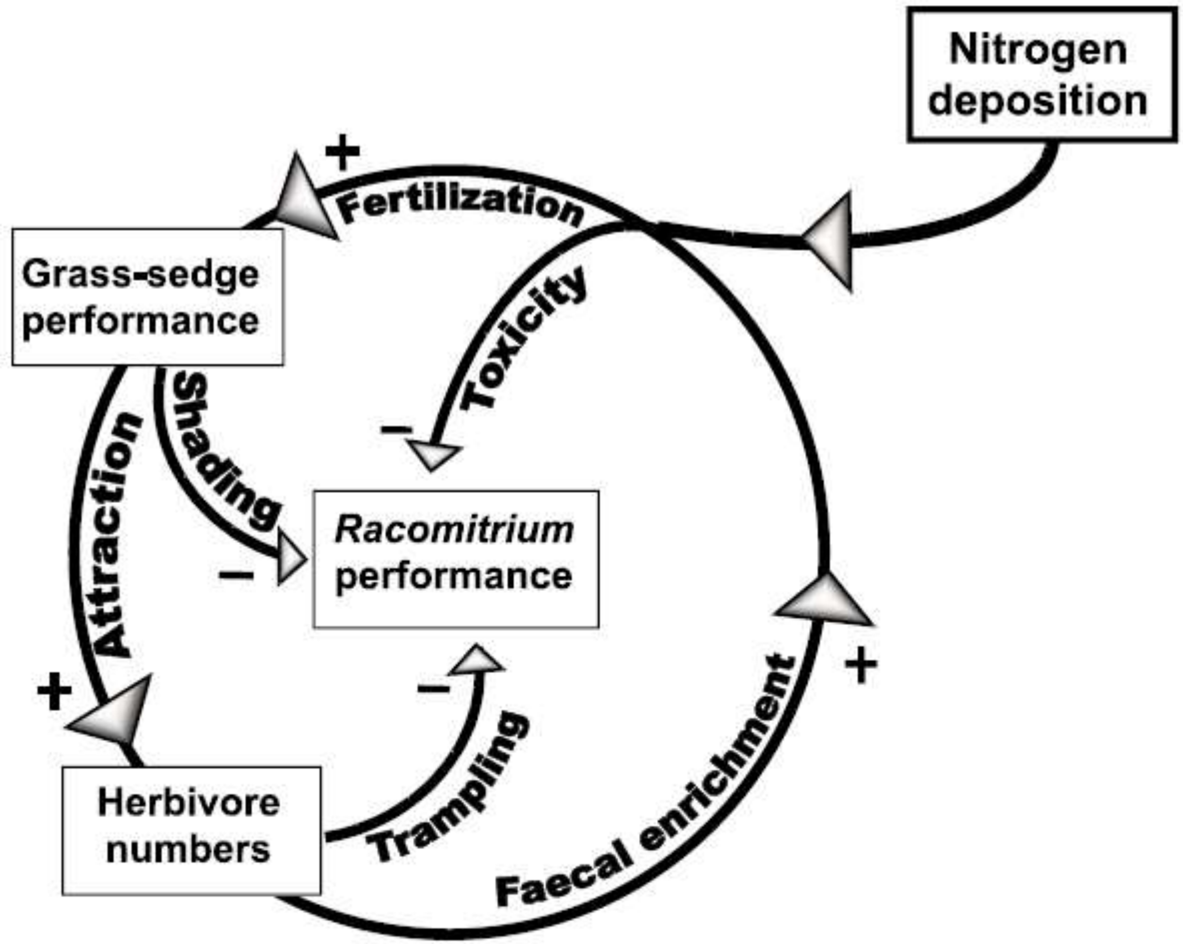

Figure 1 Conceptual model integrating impacts of nitrogen deposition and grazing. This multi-step positive feedback loop shows how atmospheric nitrogen deposition leads to the replacement of the moss *Racomitrium lanuginosum* by sedges and grasses.

van der Wal *et al.* (2003) *Ecology Letters*

Table 3. Climate change scenarios and possible impacts on the montane (alpine) ecosystem.

Scenario	**Periglacial processes**	**Soils**	**Callunetum/ *Vaccinium* heaths**	***Racomitrium* heaths**	***Juncus* communities**	**Snowbed communities**
warmer, wetter winters	reduced frost activity		expansion to higher altitudes		contraction	expansion or contraction depending on changes in amount or seasonal distribution of snowfall
warmer, wetter summers	increased slope erosion	increased vulnerability to erosion where precipitation intensity is increased, but reduced where *Racomitrium* expands; increased rates of pedological processes	expansion to higher altitudes	expansion?	contraction	
hotter, drier summers	increased wind action	increased vulnerability to erosion		increased vulnerability to erosion		
increased precipitation intensity	increased slope erosion	increased vulnerability to erosion		possible localised contraction		possible expansion of some snowbed types
increased wind speeds	increased erosion	increased vulnerability to erosion if plant cover		increased vulnerability to	increase if *Racomitrium*	

Gordon *et al.* (1998) Ambio (http://www.jstor.org/stable/4314744)

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

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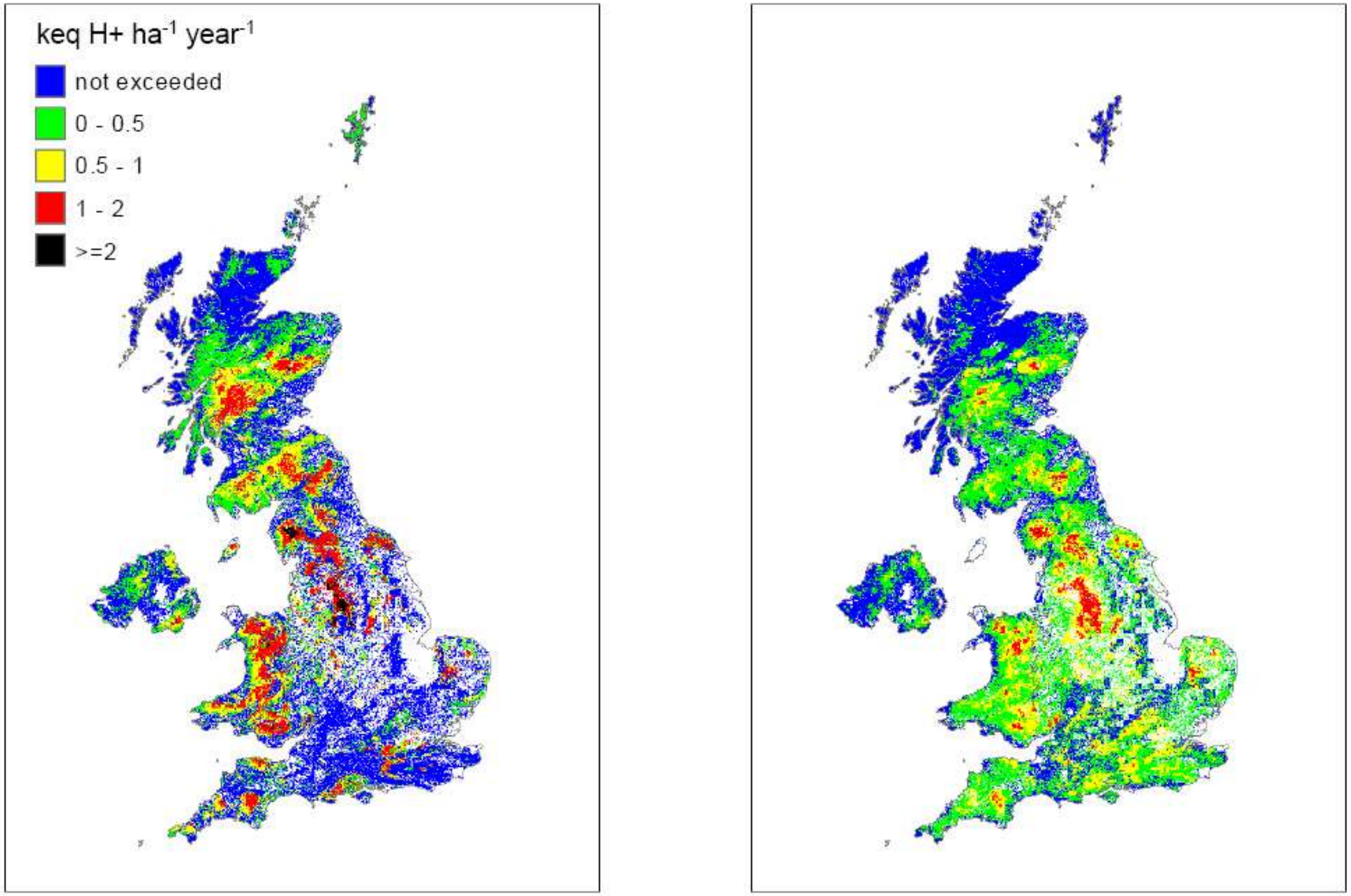
The Scottish montane

- 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 m upwards shift in vegetation zones $\rightarrow$ 93% 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)



Acidity

Nutrient nitrogen

Source: CEH and DEFRA; http://www.ceh.ac.uk/sections/er/Critical_loads.htm

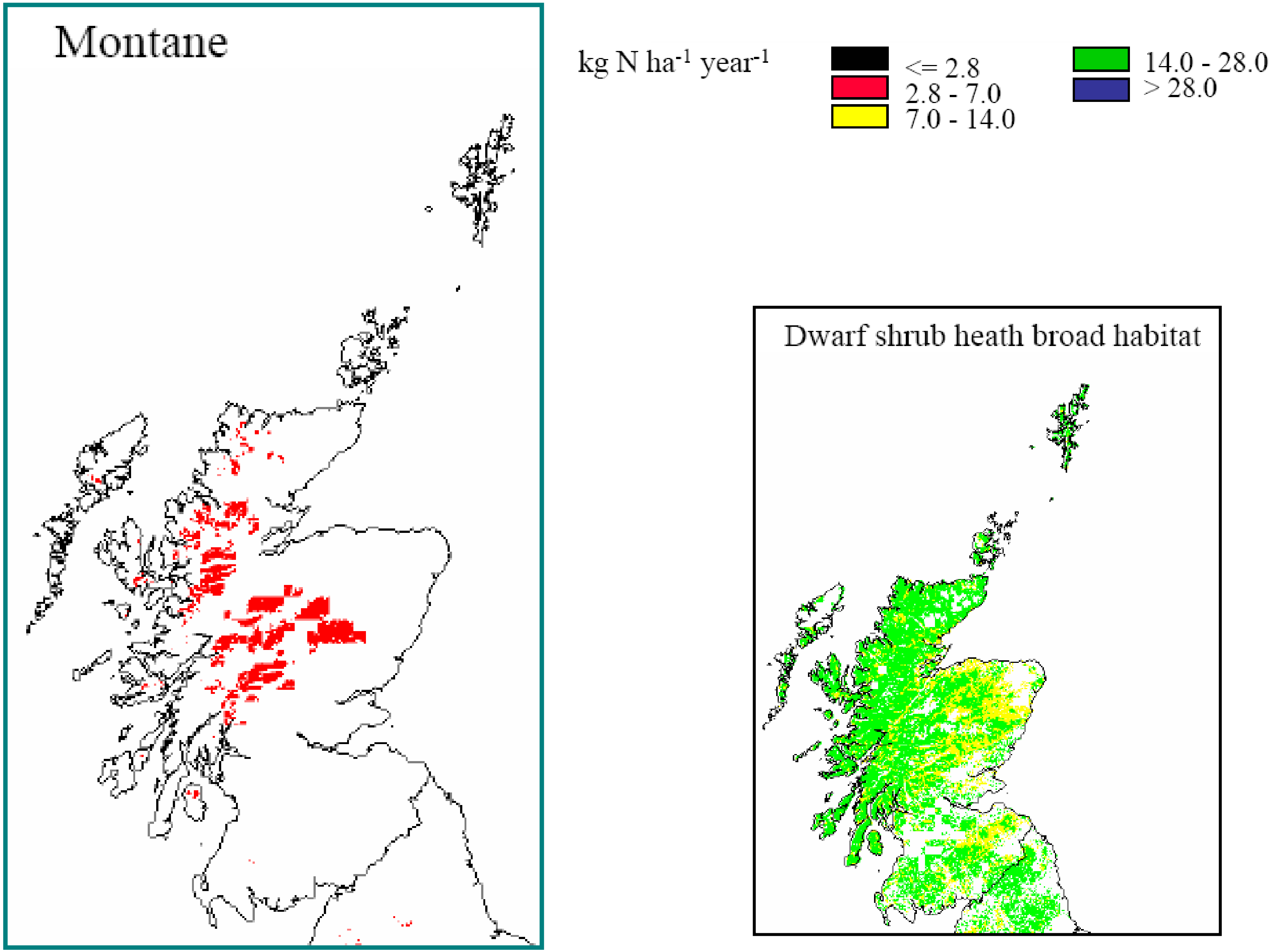
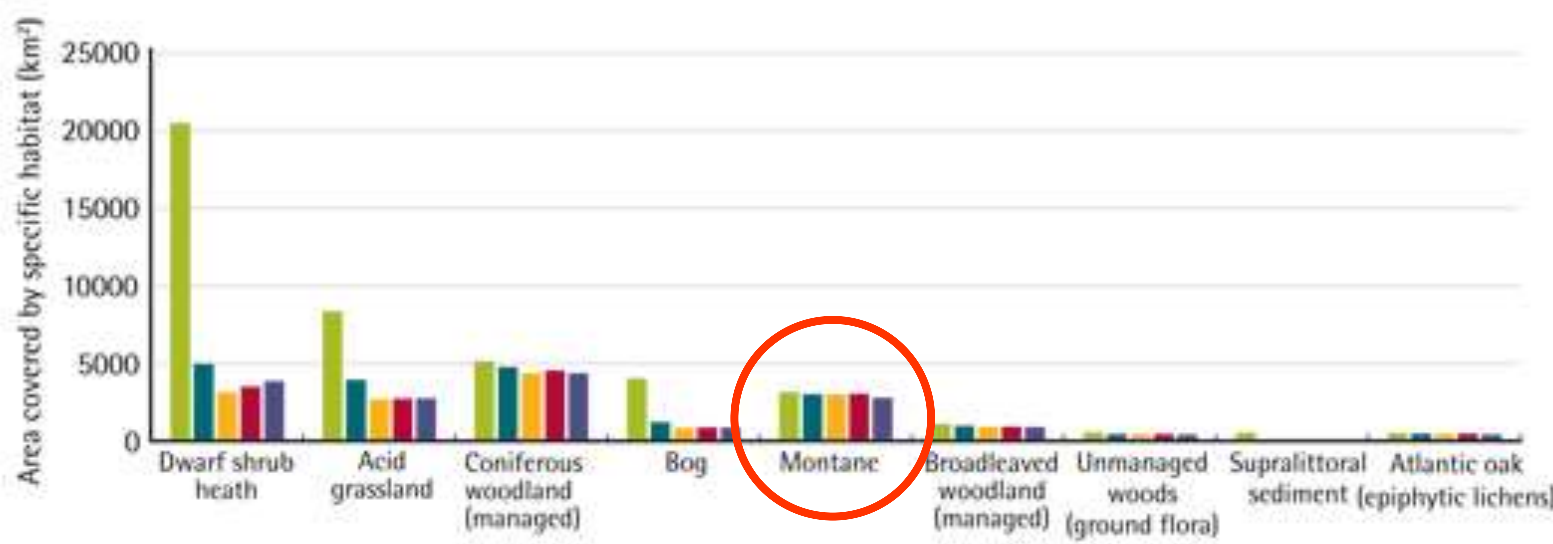

Montane
kg N ha-1 year-1
<= 2.8
2.8 - 7.0
7.0 - 14.0
14.0 - 28.0
> 28.0
Dwarf shrub heath broad habitat

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!