Chapter 4: Discussion

4.1. Potential changes in community structure due to migration and changes in competition under climate change

If the increases in temperature predicted by climate change models occur, this could facilitate an upward altitudinal shift of vegetation zones by 100 to 200m (Ellis 2004), as altitudinal zonation is partly temperature driven (Körner 1999a,b,c). Given that plants are likely to migrate at different rates under a changing climate (Pauli *et al*. 1996), what are the likely effects of such migrations? One plant which is currently limited in its distribution by altitude is *Calluna*. As discussed in Chapter 2, it was unclear whether it is currently increasing its altitudinal range or declining/retreating. During this study, it was not possible to come to any firm conclusions about other plant species due to insufficient data. No evidence was found to support an upward shift of species from lower vegetation zones.

Could the presence of *Calluna* in the sub alpine zone be a factor for determining the lower altitudinal boundary of the Scottish alpine zone? In Chapter 2 the diversity of vascular plant species was seen to increase with altitude as *Calluna* cover decreased. This suggests that the presence of *Calluna* could be a factor in the lower altitudinal distribution limits for some arctic alpine plants species in Scotland. Possible reasons for this could be the superior root competition by *Calluna* (Genney *et al*. 2000) or some form of allopathic interaction. This is an area which needs further investigation. If the growing space of arctic alpine plants is considered to be contracting, then control of *Calluna* at its upper margin may allow the downward migration of arctic alpine plants (Halloy & Mark 2003).

Seed set in *Calluna* is known to be affected by climate (see Section 2.2.4), and yet there was lack of *Calluna* seed above 850 m in 2003. Given the warm conditions, 2003 should have been a good year for seed production, even at higher altitudes (Miller & Cummins 2001). In the light of current climate change predictions (Chapter 1), which suggest warm dry summers like 2003 (at least in the east), an increase in *Calluna* seed shed may therefore not be enough to allow sufficient seed movement for upward migration of *Calluna*. Given the uncertainties in the current climatic predictions, it is also possible that wet summers such as 2002 may become more frequent. Extrapolating the results of Chapter 2 would predict a further reduction in *Calluna* seed shed under these conditions.

If current *Calluna* seed rain is insufficient for an upward movement, what about recruitment from the seedbank? An increase in mean daily temperatures, as predicted, could lead to soil warming and therefore an increase in germination of *Calluna* from the seedbank (Cummins & Miller 2002). However seedling survival may be reduced by the effects of predicted reduced snow cover leading to increased risk of frost and wind damage (see also Section 2.4.2).

Chapter 3 suggests that an increase in mean soil temperature of 0.4°C is insufficient to cause a change from facilitation to competition at high altitudes. Although Calluna was not used in the experiment described in Chapter 3, the following may be concluded from other work: If Calluna is to successfully establish at higher levels than where it is currently found, seedlings will need to be facilitated by the existing vegetation, i.e. seedlings emerging from the seed banks will be more successful with shelter from the existing vegetation (Bayfield 1996, Legg et al. 1992).

4.2. The broader context

This work has been based on the predictions of warming due to climate for Scotland. If, however, a major weakening or shut-down of the Gulf Stream occurred, temperatures may fall by up to 5°C over the following few decades (Hulme *et al*. 2002). This would potentially lead to a downward migration of vegetation due to much harsher conditions, and could lead to an increase of the area of arctic/alpine vegetation (Fosaa 2003, Fosaa *et al*. 2004).

Palaeoecological perspective

Climate change is not a new phenomenon, from the palaeoecological perspective there have been global temperature rises in the Holocene (ca. 11,000 years BP). 6,000 to 5,000 BP the climate was 4℃ warmer than currently (Guisan *et al*. 1995), predicted warming over the next century is between +1℃ and +4℃ (Hulme *et al*. 2002). As Scotland is part of an island, the alpine vegetation that is now present in the Scottish Highlands must have survived this period. Fossil tree line evidence suggests that there was an upslope movement of no more that 150 m to 200 m above the present (Huntley *et al*. 1997). However palaeoecology can not tell us anything about the mechanisms which control the extent of this shifts.

Other drivers

Climate change is not the only driver of change in the alpine zone in the Scottish Highlands, other factors could have greater impacts. There have been major changes in grazing regimes (Hester *et al*. 1996, Welsh & Scott 2000), as well as changes in ground level air pollution (Cannell *et al*. 1997, NEGTAP 2001). The combination of increased nitrogen deposition and grazing can have “dramatic” effects on mountain ecosystems (van der Wal *et al*. 2003).

4.3. Possible improvements to work carried out and recommendations for further research

If it was possible to repeat the seed dispersal study and vegetation survey in Chapter 2, the following changes and recommendations for further research are suggested:

- More sites (transects), using some (or all) of the sites which Miller and Cummins (2003) used. One of the obvious changes for the seed dispersal study would be to increase the number of transects used, either by increasing the number of transects at each site or by increasing the number of sites. Given the nature of access to the sites, increasing the number of transects may not be as easy as it sounds, as the transects used were all close to existing paths. The placing of a second transect at a suitable distance to make it independent of the first may be problematic due to the nature of the terrain. Gaining permission from landowners (particularly NTS) can be very time consuming, and may cause unexpected difficulties (year round limitations on access were imposed by NTS during the current experiment).

- More extensive vegetation surveys to investigate the relationship of altitude and *Calluna* cover on vascular plant diversity. The increase in diversity with altitude was not expected and the current study was not designed to investigate it. A more detailed investigation would require more survey points, selected at random, to give a good cover of the vegetation types in the area at the given altitude. In the present survey, points were chosen on an OS map and subsequently located on the mountain with a GPS, so the vegetation type was not known in advance, and only one quadrat was surveyed. A further investigation could survey additional quadrats at randomly selected distances and angles from the initial survey point.

- An investigation of the age structure of *Calluna* at its current altitudinal limit. This would be a relatively straightforward study to carry out. At selected sites an initial survey would be needed to determine the altitudinal limit of *Calluna* cover at that site. Although the exact nature of "altitudinal limit" could be open to interpretation, scattered individual plants may be found in sheltered locations which provide suitable micro-sites. A suggestion, for practical reasons, would be consider the upper limit as the area where *Calluna* covers less than 10% of the area due to altitude. A number of random quadrats would then be placed and e.g. ten short sections of *Calluna* stems nearest the ground (the five largest and five smallest) collected. This would be repeated at a number of sites. The stems could then be aged by cutting thin sections and counting the annual growth rings. If all stems were of a young age, then this would indicate recent establishment. However if all the stems were of an old age, this would suggest that there has been no recent recruitment to the population and that *Calluna* may be retreating down slope. A mixed age structure would suggest an undisturbed population with a regular turnover of individual plants.

If it were possible to repeat the environmental manipulation experiment described in Chapter 3, the following changes and additions would be recommended (limiting factors in brackets):

- it would be better if the target plants were already growing *in situ* and not transplanted in. This would avoid the problems of causing unnecessary disturbance to the plants, which could cause a check to growth and avoid accidental planting at the wrong depth (design)

- use of full sized ITEX OTCs. This would allow more space for finding suitable target plants *in situ* and allow better comparisons with other experiments (design & resources)

- carrying out the experiment over a longer time scale. This would allow a greater number of growing seasons and may give clearer and more robust results. It would also better allow for the effects of interannual variation of weather to be taken into account (design & resource)

- there is a need for the measurement of the environmental variables from the start of the experiment and to have sufficient suitable instruments available for replication of measurements between units (resource)

- to investigate the effects of oceanicity. It would be useful to have two or more sites on a west-east transect, sites would need to be controlled for altitude and aspect (resource)

- to further investigate the effects of diurnal temperature variation and lapse-rate by having two replicated sites at different altitudes on the same mountain, and to investigate if there are differences in the strength of plant interactions between the two altitudes. At what altitude does facilitation become more important than competition, what are the drivers, is temperature or wind strength more important? (resource)

1960's restoration of ski pistes, an inadvertent experiment in vegetation migration?

While the following does not derive directly from the work done during this project, it has come to mind during the writing of this thesis:

Re-seeding of the bulldozed ski pistes on Cairngorm with seeds of grass species not currently found at that altitude could give an opportunity to investigate the possibility of upward migration. Bayfield (1996) states that the level of cover of these species had been declining over time, but at the time of the last published survey (1992) this rate of decline had slowed. Further work should be carried out to find out if this decline in cover has continued or if it has stopped. Could this be an example of a plant species being moved to a higher altitude than it previously existed? If so, this would give an opportunity to investigate the drivers involved. In order for a species to migrate and establish at higher altitudes, the species must be able to persist in the range of environmental conditions there, including changes such as increases in wind speed (Beerling & Woodward 1994, Woodward 1993).

4.4. Implications of habitat conservation and management

The alpine zone in Scotland remains important in conservation terms and should continue to be protected. In order to detect changes in the boundaries of ecotones, it is necessary to have sufficient baseline data to allow long term monitoring to take place. The importance of good historical records has been shown by the changes detected by Grabherr *et al.* (1994) and the scarcity of other studies being able to take the same approach. It is therefore recommended that surveyors collecting species data are encouraged to provide copies of their data to biological record centres, so that they are available as a future resource.

4.5. Conclusions

No evidence was found for a significant upward movement of seed. *Calluna* seed has been found in the seedbank at higher altitudes than the surface vegetation. However this is unlikely to lead to *Calluna* colonising the alpine zone under the currently predicted levels of climate change. While the size of the *Calluna* seedbank has not changed significantly, the level of *Calluna* seed rain does appear to be declining. The results of the experiment on the balance between competition and facilitation were inconclusive. Unfortunately it was also not possible to determine the relative importance of temperature and wind as an ecological factor in the Scottish alpine zone.

It is concluded that mountain vegetation zones in Scotland will not move as whole, rather that there may be migrations of individual plant species. These migrations could have unexpected consequences and may be in directions different to expectation. Changes in zonation of plant communities are unlikely to be driven by temperature alone, however the currently employed modelling approaches are not sensitive to other factors. There is a need for more field data to understand how changes in climate will affect the distribution of alpine arctic vegetation, before more reliable models can be developed.

References

Bayfield, N.G. (1996) Long-term changes in colonization of bulldozed ski pistes at Cairn Gorm, Scotland. *Journal of Applied Ecology*, **33**, 1359-1365.

Beerling, D.J. and Woodward, F.I. (1994) Climate Change and the British Scene. *Journal of Ecology*, **82**, 391-397.

Bullock, J.M. and Clarke, R.T. (2000) Long distance seed dispersal by wind: measuring and modelling the tail of the curve. *Oecologia*, **124**, 506-521.

Cannell, M.G.R., Fowler, D. and Pitcairn, C.E.R. (1997) Climate chance and pollution impacts on Scottish vegetation. *Botanical Journal of Scotland*, **49**, 301-313.

Ellis, N. (2004) *Climate Change Impacts: The rate of climate change*. Information Note Series. Scottish Natural Heritage.

Fosaa, A.M. (2003) *Mountain vegetation in the Faroe Islands in a climate change perspective*. PhD Thesis, Lund University, S-223 62 Lund, Sweden.

Fosaa, A.M., Sykes, M.T., Lawesson, J.E. and Gaard, M. (2004) Potential effects of climate change on plant species in the Faroe Islands. *Global Ecology and Biogeography*, **13**, 427-437.

Genney, D.R., Alexander, I.J. and Hartley, S.E. (2000) Exclusion of grass roots from soil organic layers by Calluna: the role of ericoid mycorrhizas. *Journal of Experimental Botany*, **51**, 1117-1125.

Greene, D.F. and Calogeropoulos, C. (2002) Measuring and modelling seed dispersal of terrestrial plants. *Dispersal Ecology* (eds J. M. Bullock, R. E. Kenward and R. S. Hails), pp. 3-23. Blackwell, Oxford.

Guisan, A., Tessier, L., Holten, J.I., Haeberli, W. and Baumgartner, M. (1995) Understanding the impact of climate change on mountain ecosystems: An overview. In: *Potential Ecological Impacts of Climate Change in the Alps and Fennoscandian Mountains*. (eds A. Guisan, J. I. Holten, R. Spichiger and L. Tessier), pp. 15-37. Editions des Conservatoire et Jardin botaniques., Genève.

Halloy, S.R.P. and Mark, A.F. (2003) Climate-Change Effects on Alpine Plant Biodiversity: A New Zealand Perspective on Quantifying the Threat. *Arctic, Antarctic, and Alpine Research*, **35**, 248-254.

Harrison, S.J. (1997) Changes in the Scottish Climate. *Botanical Journal of Scotland*, **49**, 287-300.

Hester, A.J., Miller, D.R. & Towers, W. (1996) Landscape-scale vegetation change in the Cairngorms, Scotland, 1946-1988: Implications for land management. *Biological Conservation*, **77**, 41-51.

Hulme, M., Jenkins, G. J., Lu, X., Turnpeny, J. R., Mitchell, T. D., Jones, R. G., Lowe, J., Murphy, J. M., Hassell, D., Boorman, P., McDonald, R., and Hill, S. (2002) *Climate change scenarios for the United Kingdom: The*

UKCIP02 scientific report. Norwich, UK, Tyndall Centre for Climate Change Research, School of Environmental Science, University of East Anglia.

Huntley, B., Daniell, J.R.G. and Allen, J.R.M. (1997) Scottish vegetation history: The Highlands. *Botanical Journal of Scotland*, **49**, 163-175.

Körner, C. (1999a) *Alpine Plant Life: Functional plant ecology of high mountain ecosystems.* Springer-Verlag, Berlin.

Körner, C. (1999b) The climate plants experience. In: *Alpine Plant Life: Functional plant ecology of high mountain ecosystems.* pp. 31-45. Spinger, Berlin.

Körner, C. (1999c) Alpine plants: stressed or adapted? In: *Physiological Plant Ecology.* (eds M. C. Press, J. D. Scholes and M. G. Barker), Blackwell Science, Oxford.

Körner, C. (2000) The alpine life zone under global change. *Gayana Botánica*, **57**, 1-17.

Legg, C.J., Maltby, E. & Proctor, M.C.F. (1992) The ecology of severe moorland fire on the North York Moors - seed distribution and seedling establishment of *Calluna vulgaris*. *Journal of Ecology*, **80**, 737-752.

Miller, G.R. and Cummins, R.P. (2003) Soil seed banks of woodland, heathland, grassland, mire and montane communities, Cairngorm Mountains, Scotland. *Plant Ecology*, **168**, 225-266.

NEGTAP (2001) *Transboundary Air Pollution: Acidification, Eurtophication and Ground-level Ozone in the UK.* Prepared by the National Expert Group on Transboundary Air Pollution (NEGTAP) at CEH Edinburgh on behalf of the UK Department for Environment, Food and Rural Affairs (Defra), Scottish Executive, The National Assembly for Wales/Cynulliad Cenedlaethol Cymru, Department of the Environment for Northern Ireland. ISBN 1 870393 61 9. Defra, London, UK.

van der Wal, R., Pearce, I.S.K., Brooker, R., Scott, D., Welch, D. & Woodin, S.J. (2003) Interplay between nitrogen deposition and grazing causes habitat degradation. *Ecology Letters*, **6**, 141-146.

Welch, D. and Scott, D. (2000). Seasonal and spatial patterns in sheep grazing on a high-level plateau in the Grampian mountains Scotland. *Scottish Geographical Journal*, **116**, 299–314.

Woodward, F.I. (1993) The Lowland-To-Upland Transition Modelling Plant-Responses to Environmental-Change. *Ecological Applications*, **3**, 404-408.