APPENDIX 1A.1

GRAZING OF HEATHER MOORLAND VEGETATION

H.F. Adamson & C.N.R. Critchley

ADAS Redesdale, Rochester, Otterburn, Newcastle upon Tyne

NE19 1SB, UK

DEFINITIONS OF HEATHER MOORLAND

Heather moorland comprises a range of habitats with a dwarf shrub component. The main focus of this review is on the UK Biodiversity Action Plan Priority Habitats upland (wet and dry) dwarf shrub heath and blanket bog as well as other mire types and upland acid grassland. Montane heath (> 600m asl) is not included.

Upland heath is defined as having at least 25% cover of dwarf shrub on peat less than 0.5m deep. Generally it lies between enclosed agricultural land at around 250m altitude and the montane or alpine zone at 600m. Typical species include *Calluna vulgaris, Nardus stricta, Deschampsia flexuosa* and *Carex nigra* with *Molinia caerulea*, *Erica tetralix* and *Sphagnum* species particularly common on the wet heaths. Grasslands are defined as having less than 25% dwarf shrub heath and may result from degradation of dwarf shrub heath. The dry heath communities are *Calluna - Erica cinerea* (H10), *Calluna vulgaris - Vaccinium myrtillus* (H12), *Vaccinium myrtillus - Deschampsia flexuosa* (H18) and *Calluna vulgaris - Vaccinium myrtillus - Sphagnum capillifolium* (H21), along with several more local community types (Rodwell 1991). The principle wet heath community is *Scirpus cespitosus - Erica tetralix* (M15), with the more localised *Erica tetralix - Sphagnum compactum* (M16) (Rodwell 1991). Acid grasslands are *Festuca ovina - Agrostis capillaris – Galium saxatile* (U4), *Nardus stricta – Galium saxatile* (U5) and *Juncus squarrosus – Festuca ovina* (U6) (Rodwell 1992).

Blanket bog also has at least 25% dwarf shrub cover, but peat is deeper than 0.5m. It is predominantly ombrotrophic (rain fed) and the peat and associated vegetation typical covers or 'blankets' vast areas of land in a cool, wet oceanic climate. It may also contain pockets of minerotrophic (ground water fed) communities. Typical species include *C. vulgaris, Eriophorum vaginatum, E. angustifolium*, *Sphagnum* species. The principle plant communities are *Scirpus cespitosus – Eriophorum vaginatum* (M17), *Erica tetralix – Sphagnum papillosum* (M18), *Calluna vulgaris – Eriophorum vaginatum* (M19), *Molinia caerulea – Potentilla erecta* (M25) and various bog pool communities (Rodwell 1991). Degraded blanket bog may be dominated by *Eriophorum vaginatum* (M20), *Juncus squarrosus* (U6) or extensive bare areas.

For more detailed descriptions see Backshall *et al*. (2001).

Upland heath and mire habitats are of international conservation significance (Usher & Thompson 1993; Thompson *et al.* 1995). Increased grazing pressure has been identified as a major cause of heather moorland degradation in England and Wales (Thompson *et al.* 1995; Fuller & Gough 1999).

LIVESTOCK GRAZING PREFERENCES

Livestock grazing preferences (taken here to include browsing of dwarf shrubs) strongly depend on the range of plant species available in the sward, their relative abundance and spatial distribution and seasonal variation in palatability. In a study of blanket bog, sheep grazed *M. caerulea*, *Trichophorum cespitosum* and some *D. flexuosa, Agrostis canina* and *Carex* spp during the summer, all of which have high digestibility at this time of year. In the autumn, as *M. caerulea*, *T. cespitosum* and other grasses and sedges died off and became less digestible, sheep began to graze *C. vulgaris* and *E. vaginatum* (Grant *et al.* 1976). In spring (after wintering off-site), *C. vulgaris* and *E. vaginatum* continued to be the main components of the diet with immature *E. vaginatum* flowers being particularly favoured by sheep (Grant *et al.* 1987). Sheep might also graze *Vaccinium myrtillus* particularly heavily in the autumn (Welch 1998).

(Hester & Baillie 1998) showed that red deer graze heather to a similar extent as sheep, although they graze on heather more intensively in autumn than do sheep. Deer will graze mature heather (Hewson 1976). Deer and goats will both graze graminoids in preference to heather (Fraser & Gordon 1997). Mountain hares (*Lepus timidus*) also graze heather, especially in its pioneer growth stage (Hewson 1976).

Cattle have been shown to have similar preferences to sheep when on blanket bog and upland heath, but their ability to selectively graze is less. The distribution of the sward components also affects cows' ability to select the preferred species. Where desirable species are interspersed amongst less desirable species it is more difficult for the cattle to pick them out than if species are aggregated in patches. Cattle are more likely to eat dead plant material than sheep, again because of their reduced ability to graze selectively at small scales. Cattle are more reluctant to graze *C. vulgaris* than are sheep but will do so when preferred species such as *M. caerulea*, grasses and sedges are not available. Cattle graze more of the shoot than sheep, potentially causing more damage to *C. vulgaris*, with the risk also of uprooting plants (Grant *et al.* 1987). In northern Spain, cattle grazed on open pasture in spring and summer but selected *C. vulgaris* and *Ulex* sp. in late summer and autumn (Mandaluniz *et al*. 2005). In *M. caerulea* grassland, cattle utilised *M. caerulea* more than other grasses in summer, resulting in reduction of its biomass, cover and rate of leaf extension (Grant *et al*. 1996a).

Cattle also ingest more *N. stricta* than sheep (Common *et al*. 1998). A reduction of the number of tussocks, leaf extension and nutrient reserves was detected when cattle grazed *N. stricta* at a rate such that between tussock mean sward height was maintained at 4.5cm. Over 5 years this brought about a reduction in *N. stricta* cover from 55% to 30% (Grant *et al.* 1996b). However, Fraser & Gordon (1997) showed that deer and goats preferred the inter-tussock vegetation in *N. stricta* swards to *N. stricta* itself.

EFFECTS OF GRAZING ON HEATHER MOORLAND

The primary effect of grazing on individual plants is removal of above-ground biomass by defoliation. Grazing affects not only the plant species selected by grazing animals but also the structure of the whole plant community by modifiying competition and its interaction with other factors (Welch & Scott 1995; Yeo & Blackstock 2002). The morphological response of *C. vulgaris* plants to light grazing is the conversion of a few of the uppermost short shoots into new long shoots and the emergence of new clusters of shoots from lower woody parts. More intensive or continuous grazing pressure results in more new shoot clusters (Mohamed & Gimingham 1970) but heavy grazing by sheep has been widely shown to reduce heather cover in favour of grasses and sedges (e.g. Anderson & Yalden, 1981; Grant *et al.* 1985; Moss 1989; Dodgshon & Olsson 2006). Young *C. vulgaris* plants are less productive and more susceptible to grazing than mature plants (Nolan *et al*. 1995; Kirkham & Milne 2000; Milne *et al*. 2002). Bardgett et al. (1995) reported that much of the heather on moorland in England and Wales was suppressed or damaged and attributed this to heavy grazing as a result of high sheep stocking densities (> 1.5 ewes ha^{-1}). In Scotland, grazing by red deer (*Cervus elaphus*) can reduce cover of *C. vulgaris*, particularly if it is old and if deer densities are above 2 HE (hind-equivalents) ha^{-1} (Grant *et al.* 1981).

Various studies have been undertaken in order to determine sustainable sheep grazing levels. Grant *et al.* (1978) showed that grazing of 40% or 80% by weight of the current season's shoots of *C. vulgaris* by sheep in summer or autumn resulted in an overall reduction in the standing crop after three years. Modelling has shown that pioneer and early-stage building *C. vulgaris* would tolerate only 16% utilisation in the summer and 24% in the autumn, while that recently burnt would benefit from no grazing at all (Palmer 1997). Longer term impacts of sustained grazing, as modelled by Read *et al.* (2002) also indicated that sustainable utilisation rates would be lower than those suggested by Grant *et al.*

Various sheep stocking levels have been recommended to maintain heather moorland, for example 0.7 and 1.5 ewes ha^{-1} for dwarf shrub heath in agri-environment schemes in northern England[1]. Even at a relatively low stocking rate, however, localised heavy grazing can occur, notably at heather:grass interfaces, i.e. along moorland edges (Simpson *et al.* 1998; Gordon *et al.* 2004). *C. vulgaris* adjacent to palatable *Agrostis-Festuca* grassland is more likely to be eaten by sheep or deer than that close to less palatable species such as *M. caerulea* and *N. stricta* and more again than that in pure stands (Palmer *et al.* 2003). Sheep also spend more time grazing *C. vulgaris* associated with many small grass patches than few larger patches (Clarke *et al.* 1995a). Hester & Baillie (1998) showed that *C. vulgaris* utilisation by sheep and deer declined with increasing distance from grass. The spatial distribution of forage species and its interaction with grazing animals has a profound effect on moorland vegetation dynamics and models have been developed to

[1] http://www.defra.gov.uk/erdp/docs/national/annexes/annexx/lakedis1.htm (accessed 31/01/07)

describe and predict the spatial effects of grazing particularly by deer and sheep at *C. vulgaris*-grass interfaces (Palmer & Hester 2000; Palmer *et al.* 2004) and by sheep in more complex vegetation mosaics (Gardner 2002).

The effect of grazing interacts with nitrogen levels by altering competition between moorland species (Hartley & Amos 1999). Increased nitrogen increases growth of *C. vulgaris*, but it may then be preferentially grazed so that cover decreases allowing grasses (*N. stricta*, *F. ovina* and *Agrostis* spp.) to invade (Hartley & Mitchell 2005). Alonso *et al.* (2001) also found that at low levels of grazing and elevated N, *C. vulgaris* would out-compete grass species, but at high levels of grazing, gaps created in the *C. vulgaris* canopy were filled by grasses whose growth was enhanced by the elevated N levels. In addition to grazing, the effects of other management practices (burning, mowing and litter removal) and heather beetle (*Lochmaea suturalis*) outbreaks are more severe under elevated atmospheric N deposition levels (Terry *et al.* 2004). Moorland moss species are also thought to be declining as a result of the interaction between increased N deposition and grazing (van der Wal *et al.* 2003). In an analysis of several grazing experiments, Pakeman (2004) found that few species showed a consistent response to grazing (*D. flexuosa* and *M. caerulea* amongst those declining with increased grazing intensity) but the response of most (including *N. stricta*) varied with site productivity.

A secondary effect of grazing animals is from dung deposition. Shepherd *et al.* (2000) found that there is less incorporation of dung into the moorland substrate than that of grassland. This would result in less efficient nutrient cycling in moorland but dung is likely to persist for longer and could therefore provide a significant regeneration niche. On moorland, monocots are more likely than dicots to germinate in dung. However, *Cerastium holosteoides, Lolium perenne, Poa annua, P. pratensis, Rumex acetosella, Stellaria media* and *Veronica serpyllifolia* have been shown to increase cover as a result of seedling establishment on dung. *C. vulgaris* seedlings were more common after cattle grazing than sheep grazing, which was partly attributable to establishment on dung (Welch 1985). Cattle also have a trampling affect (Welch & Scott 1995), and might have been used in the past to break up moorland (and woodland) in preparation for agricultural use (Fenton 1935).

MANIPULATION OF GRAZING REGIMES FOR MOORLAND RESTORATION

Restoration of heather moorland vegetation by grazing has focussed primarily on *C. vulgaris* communities damaged by high stocking levels of sheep and cattle (Anderson & Yalden 1981). Restoration management can include practices such as burning, cutting, herbicide application or reseeding (Anderson *et al.* 1997; Marrs *et al.* 2004) but this review focuses on the effects of grazing.

Various studies have investigated the effects of reducing sheep numbers. (Bardgett et al. 1995) suggested that sheep stocking levels above 1.5-2 ewes ha^{-1} would suppress *C. vulgaris*. Pakeman *et al.* (2003) found that reducing stocking levels to 0.8-0.9 sheep ha^{-1} on a degraded dry heath in north-east Scotland benefited dwarf shrubs and reduced grass cover. Adamson *et al.* (2001) showed that on wet heath in the north-east of England, reducing the stocking rate from 2.1 to 1.5 or 0.7 ewes ha^{-1} increased the vigour but not the cover of *C. vulgaris* where it was already present. Where *C. vulgaris* had been lost, the reduced stocking rates led to an increase of the cover of the grasses *M. caerulea* and *N. stricta*. Similarly, Hulme *et al.* (2002), showed that a stocking level between 0.7 and 1.4 sheep/ha maintained or increased remnant *C. vulgaris* in a *M. caerulea* dominated community and concluded that complete removal of sheep would be detrimental. Hetherington *et al*. (2002) also found that *C. vulgaris* cover was maintained at 1.5 sheep ha^{-1} but not enhanced at 1.0 sheep ha^{-1}. This is supported by restoration experiments where grazed plots had a greater complement of moorland species and ungrazed plots had more *M. caerulea* and other grassland species (Milligan *et al*. 2004). However, in the Scottish Highlands, sheep were completely removed from 11 upland sites with a wide range of vegetation types. At five sites vegetation height increased and dwarf shrub patches expanded, while floristic composition hardly changed. At the remaining sites, few changes took place, possibly as a result of burning management and increased deer numbers (Hope *et al.* 1996). On ombrotrophic mire in the north-east of England, complete removal of sheep resulted in the decline in cover of some characteristic species but only at the drier edges of the mire (Smith *et al.*

2003). On *V. myrtillus* dominated moorland in the Peak District, removal of grazing resulted in a dramatic increase in *V. myrtillus* height (Welch 1998).

Hulme *et al.* (1999) found that cessation of grazing on *Agrostis-Festuca* grassland resulted in an increase in grazing-intolerant species, such as *M. caerulea*, *D. flexuosa* and dwarf shrubs (if already present), whereas maintaining the sward at 6cm high prevented *M. caerulea* and *N. stricta* from increasing. On the Isle of Rum in western Scotland, deer were excluded for 20-40 years. Few changes in species richness were found on unproductive vegetation (*C. vulgaris* and *M. caerulea* heaths) but, on productive (*Agrostis-Festuca*) grassland, species richness declined as prostrate herb species were lost and *Festuca rubra* became dominant (Virtanen *et al.* 2002).

Light grazing (in line with existing agri-environment scheme prescriptions) of mixed *Calluna* / *Molinia* wet heaths in the Yorkshire Dales and Peak District, resulted in an increase in the bog-moorland characteristics of the community (Marrs *et al.* 2004). In contrast, grazing at these levels had little effect on *M. caerulea* dominated wet heath. Simpson *et al.* (1998) found that sheep stocking rates of between 0.5 and 1 ewe ha^{-1} in association with a burning programme maintained the heather moorland in Orkney and Shetland.

In some cases stocking rate has been increased to reduce cover of dominant grasses. Heavy summer grazing reduces the cover of *M. caerulea* (Grant *et al.* 1963; Hulme *et al.* 2002) and *N. stricta* can also be reduced by heavy grazing by cattle (Grant *et al.* 1996b). Cattle have also been used to reduce *M. caerulea* cover, litter and tussocks on blanket bog in Ireland (Dunne & Doyle 1998).

The timing of grazing can also affect the vegetation response. Sheep are most likely to graze *C. vulgaris* in autumn (Clarke *et al*., 1995b) and summer-only was predicted by a spatially-explicit model to be most beneficial grazing regime for *C. vulgaris* (Gardner 2002). On the Isle of Rum, the introduction of cattle winter grazing on an *M. caerulea* dominated sward increased the availability of other forage species (Hodgson *et al.* 1991). However, Hulme *et al*. (2002) found that winter-only grazing was detrimental on *M. caerulea* dominated wet heath in north-east England and, on blanket bog, year-round sheep grazing reduced *C. vulgaris* and *E. vaginatum* cover more than summer-only grazing (Grant et al., 1985). In contrast, Pakeman *et al.* (2003) found that as long as *C. vulgaris* utilisation levels were below 20% (achieved via sheep stocking levels of 0.8-0.9 sheep ha^{-1} $year^{-1}$), then vegetation condition was improved irrespective of the timing. On *V. myrtillus* dominated moorland in the Peak District, *V. myrtillus* was not affected by timing of grazing, but *Empetrum nigrum* benefited from not being grazing in the winter (Welch 1998).

Variation among sites in the response to grazing (also demonstrated in this review) means that blanket stocking rates are inappropriate for maintaining the condition of *C. vulgaris* or overall biodiversity (Gordon *et al.* 2004) and it might be better to base stocking levels on utilisation rates in the field rather than sheep numbers per se (Pakeman *et al.* 2003). Particular consideration should be given to the species composition of the plant community as this can affect the utilisation of *C. vulgaris* (Hulme *et al.* 2002) and its dominance (Welch & Scott 1995). In experiments to control *M. caerulea* by herbicide application and grazing, Marrs *et al.* (2004) found varying responses of apparently similar vegetation types in different regions, which highlighted the importance of understanding the floristic composition of the site before undertaking restoration. Vandvik *et al.* (2005) also found that responses to burning and grazing were dependent on the initial composition of the vegetation as did Hulme *et al.* (1999) in a grazing study of *Agrostis-Festuca* grassland. In the latter, site productivity and the presence of species such as *M. caerulea* and *N. stricta*, which are able to replace the more palatable grasses, were important.

Under-grazing, as well as over-grazing, can cause environmental damage (El Aich & Waterhouse 1999). Merely reducing sheep numbers, as shown in examples above, is often not sufficient to effect an improvement in the habitat and might be detrimental to other taxa (Gordon *et al.* 2004). This is partly because a variety of ecological processes will occur at different scales (Rushton *et al.* 1996). For example, low stocking rates suitable for *C. vulgaris* might be damaging to *V. myrtillus* moorland, and grazing pressure might need to be varied spatially in order to maintain a diversity of vegetation types

(Welch 1998). Reduced stock numbers is also a threat to lowland heathland in the Netherlands (Bokdam & Gleichman 2000).

If component species are still present in the plant community, grazing exclusion alone might result in more successful restoration than mechanical methods (Littlewood *et al*. 2006). However, other measures will often be necessary to restore moorland vegetation in addition to reducing or removing sheep (Moss 1989; Gordon *et al.* 2004). Complex management programs including disturbance by burning and grazing should be undertaken at various spatial scales (Vandvik *et al.* 2005).

KNOWLEDGE GAPS

Much is understood about the grazing preferences of sheep and, to a lesser extent, of cows on moorland vegetation. A reasonable amount of research into the effects of sheep grazing at various stocking rates on moorland has been carried out, although the outcomes tend to be site dependant. Less is known about the effects of cattle or mixed cattle and sheep grazing on heathland and moorland species.

Better understanding is required of the role of grazers in maintaining habitats in favourable condition (El Aich & Waterhouse 1999) and the use of grazers for long-term biodiversity enhancement at landscape or catchment scales (Hadjigeorgiou *et al.* 2005). It is important to understand the varying spatial scales at which dietary choice and plant competition operate, from small patches to the natural or enforced home ranges of grazing animals (Gordon *et al*. 2004; Palmer *et al*. 2003, 2004; Palmer & Hester 2000; Rook *et al*. 2004). Spatial heterogeneity can promote plant species co-existence (Janecek & Leps 2005), which might be achievable by varying livestock type and densities and the timing of grazing.

Restoration processes can take a long time and they should be prepared for, and monitored accordingly (Marrs *et al.* 2004). Potential interactions with climate change at all scales also need to be considered (Gordon *et al.* 2004; Milne & Hartley 2001).

REFERENCES

Adamson, H.F., Ross, S.Y. & Gardner, S.M. (2001). The response of upland wet heath to ESA stocking rates: a heft scale approach. In Biodiversity, plant structure and vegetation heterogeneity: interactions with the grazing herbivore, Crianlarich. November 2002.

Alonso, I., Hartley, S.E. & Thurlow, M. (2001). Heather-grass competition on Scottish moorlands: Interacting effects of nutrient enrichment and grazing regime. Journal of Vegetation Science 12, 249-260.

Anderson, P., Tallis, J.H. & Yalden, D.W. (1997). Restoring moorland: Peak District Moorland Management Project. Phase III Report. Peak Park Joint Planning Board, Bakewell, UK.

Anderson, P. & Yalden, D.W. (1981). Increased sheep numbers and the loss of heather moorland in the peak district, England. Biological conservation 20, 195-213.

Backshall, J., Manley, J. & Rebane, M.E. (2001). The upland management handbook. English Nature, Peterborough, UK.

Bardgett, R.D., Marsden, J.H. & Howard, D.C. (1995). The extent and condition of heather on moorland in the uplands of England and Wales. Biological Conservation 71, 155-161.

Bokdam, J. & Gleichman, J.M. (2000). Effects of grazing by free-ranging cattle on vegetation dynamics in a continental north-west European heathland. Journal of Applied Ecology 37, 415-431.

Clarke, J.L., Welch, D. & Gordon, I.J. (1995a). The influence of vegetation pattern on the grazing of heather moorland by red deer and sheep. I. The location of animals on grass/heather mosaics. Journal of Applied Ecology 32, 166-176.

Clarke, J.L., Welch, D. & Gordon, I.J. (1995b). The influence of vegetation pattern on the grazing of heather moorland by red deer and sheep. II. The impact on heather. Journal of Applied Ecology 32, 177-186.

Common, T.G., Wright, I.A. & Grant, S.A. (1998). The effect of grazing by cattle on animal performance and floristic composition in Nardus-dominated swards. Grass and Forage Science 53, 260-269.

Dodgshon, R.A. & Olsson, G.A. (2006). Heather moorland in the Scottish Highlands: the history of a cultural landscape, 1600–1880. Journal of Historical Geography 32, 21-37.

Dunne, F. & Doyle, G. (1998). Changes in Molinia-dominated vegetation due to cattle grazing in Killarney, Co. Kerry. Biology and Environment 98B, 45.

El Aich, A. & Waterhouse, A. (1999). Small ruminants in environmental conservation. Small Ruminant Research 34, 271-287.

Fenton, E.W. (1935). The Transition from woodland and moorland to grassland in the Spey Valley and elsewhere. Journal of Ecology 23, 56-68.

Fraser, M.D. & Gordon, I.J. (1997). The diet of goats, red deer and South American camelids feeding on three contrasting scottish upland vegetation communities. Journal of Applied Ecology 34, 668-686.

Fuller, R.J. & Gough, S.J. (1999). Changes in sheep numbers in Britain: implications for bird populations - Cultural Landscapes. Biological Conservation 91, 73-89.

Gardner, S.M. (2002) Managing upland vegetation for sheep and conservation. In: Conservation pays? Reconciling environmental benefits with profitable grassland systems (ed. J. Frame). Occasional Symposium of the British Grassland Society, No. 36, pp. 115-118. British Grassland Society, Reading.

Gordon, I.J., Hester, A.J. & Festa-Bianchet, M. (2004). The management of wild large herbivores to meet economic, conservation and environmental objectives. Journal of Applied Ecology 41, 1021-1031.

Grant, S.A., Barthram, G.T., Lamb, W.I.C. & Milne, J.A. (1978). Effects of season and level of grazing on the utilisation of heather by sheep. I. Responses of the sward. Grass and Forage Science 33, 289-300.

Grant, S.A., Bolton, G.R. & Torvell, L. (1985). The responses of blanket bog vegetation to controlled grazing by hill sheep. Journal of Applied Ecology 22, 739-751.

Grant, S.A., Hamilton, W.J. & Souter, C. (1981). The responses of heather dominated vegetation in North East Scotland to grazing by red deer. Journal of Ecology 69, 189-204.

Grant, S.A., Hunter, R.F. & Cross, C. (1963). The effects of burning Molinia-dominant communities. Grass and Forage Science 18, 249-257.

Grant, S.A., Suckling, S.A., Smith, H.K., Torvell, L., Forbes, T.D.A. & Hodgson, J. (1987). Comparative studies of diet selection by sheep and cattle: blanket bog and heather moor. Journal of Ecology 75, 947-960.

Grant, S.A., Torvell, L., Common, T.G., Sim, E.M. & Small, J.L. (1996a). Controlled grazing studies on Molinia grassland: effects of different seasonal patterns and levels of defoliation on Molinia growth and responses of swards to controlled grazing by cattle. Journal of Applied Ecology 33, 1267-1280.

Grant, S.A., Torvell, L., Sim, E.M., Small, J.L. & Armstrong, R.H. (1996b). Controlled grazing studies on Nardus grassland: effects of between-tussock sward height and species of grazer on Nardus utilisation and floristic composition in two fields in Scotland. Journal of Applied Ecology 33, 1053-1064.

Grant, S.A., W.I.C., L., Kerr, C.D. & Bolton, G.R. (1976). The utilisation of blanket bog vegetation by grazing sheep. Journal of Ecology 13, 857-869.

Hadjigeorgiou, I., Osoro, K., Fragoso de Almeida, J.P. & Molle, G. (2005). Southern European grazing lands: Production, environmental and landscape management aspects. Livestock Production Science 96, 51-59.

Hartley, S.E. & Amos, L. (1999). Competitive interactions between Nardus stricta L. and Calluna vulgaris (L.) Hull: the effect of fertilizer and defoliation on above- and below-ground performance. Journal of Ecology 87, 330-340.

Hartley, S.E. & Mitchell, R.J. (2005). Manipulation of nutrients and grazing levels on heather moorland: changes in Calluna dominance and consequences for community composition. Journal of Ecology 93, 990-1004.

Hester, A.J. & Baillie, G.J. (1998). Spatial and temporal patterns of heather use by sheep and red deer within natural heather/grass mosaics. Journal of Applied Ecology 35, 772-784.

Hetherington, S.L., McLean, B.M.L., Gardner, S.M., Wildig, J. & Griffiths, J.B. (2002) The impact of Environmentally Sensitive Areas policy in relation to conservation and farming objectives. In: Conservation pays? Reconciling environmental benefits with profitable grassland systems (ed. J. Frame). Occasional Symposium of the British Grassland Society, No. 36, pp. pp. 85-88. British Grassland Society, Reading.

Hewson, R. (1976). Grazing by mountain hares Lepus timidus L., red deer Cervus elaphus L. and red grouse Lagopus L. scoticus on heather moorland in north-east Scotland. Journal of Applied Ecology 13, 657-666.

Hodgson, J., Forbes, T.D.A., Armstrong, R.H., Beattie, M.M. & Hunter, E.A. (1991). Comparative Studies of the Ingestive Behaviour and Herbage Intake of Sheep and Cattle Grazing Indigenous Hill Plant Communities. Journal of Applied Ecology 28, 205-227.

Hope, D., Picozzi, N., Catt, D.C. & Moss, R. (1996). Effects of reducing sheep grazing in the Scottish Highlands. Journal of Range Management 49, 301-310.

Hulme, P.D., Merrell, B.G., Torvell, L., Fisher, J.M., Small, J.L. & Pakeman, R.J. (2002). Rehabilitation of degraded Calluna vulgaris (L.) Hull-dominated wet heath by controlled sheep grazing. Biological Conservation 107, 351-363.

Hulme, P.D., Pakeman, R.J., Torvell, L., Fisher, J.M. & Gordon, I.J. (1999). The effects of controlled sheep grazing on the dynamics of upland Agrostis-Festuca grassland. Journal of Applied Ecology 36, 886-900.

Janecek, S. & Leps, J. (2005). Effect of litter, leaf cover and cover of basal internodes of the dominant species Molinia caerulea on seedling recruitment and established vegetation. Acta Oecologica 28, 141-147.

Kirkham, F.W & Milne, J.A. (2000). Progress towards defining ecologically-sustainable grazing management: the 'Moorland Biomass' and 'Heather Suppression' projects. Aspects of Applied Biology 58, 151-158.

Littlewood, N.A., Pakeman, R.J. & Woodin, S.J. (2006) A field assessment of the success of moorland restoration in the rehabilitation of whole plant assemblages. Applied Vegetation Science 9, 295-306.

Mandaluniz, N., Oregui, L.M. & Aldezabal, A. (2005) Utilisation of gorse and heather communities by cattle in mountain grazing. In: Sylvopastoralism and Sustainable Land Management (eds Mosquera-Losada, M. R.; Rigueiro-Rodriguez, A.; McAdam, J.), pp.157-159. CABI Publishing, Wallingford.

Marrs, R.H., Phillips, J.D.P., Todd, P.A., Ghorbani, M. & Le Duc, M.G. (2004). Control of Molinia caerulea on upland moors. Journal of Applied Ecology 41, 398- 411.

Milligan, A.L., Putwain, P.D., Cox, E.S., Ghorbani, J., Le Duc, M.G. & Marrs, R.H. (2004). Developing an integrated land management strategy for the restoration of moorland vegetation on Molinia caerulea-dominated vegetation for conservation purposes. Biological Conservation 119, 371-385.

Milne, J.A. & Hartley, S.E. (2001). Upland plant communities - sensitivity to change. CATENA 42, 333-343.

Milne, J.A., Pakeman, R.J., Kirkham, F.W., Jones, I.P. & Hossell, J.E. (2002). Biomass production of upland vegetation types in England and Wales. Grass and Forage Science 57, 373-388.

Mohamed, B.F. & Gimingham, C.H. (1970). The Morphology of Vegetative Regeneration in Calluna vulgaris. New Phytologist 69, 743-750.

Moss, R. (1989). Management of heather for game and livestock. Botanical Journal of the Linnean Society 101, 301-306.

Nolan, A.J., Henderson, D.J. & Merrell, B.G. (1995). The vegetation dynamics of wet heaths in relation to sheep grazing intensity. In: Heaths and Moorland: Cultural Lanscapes (eds D.B.A. Thompson, A.J. Hester & M.B. Usher), pp.174-179. HMSO, Edinburgh.

Pakeman, R.J. (2004). Consistency of plant species and trait responses to grazing along a productivity gradient: a multi-site analysis. Journal of Ecology 92, 893-905.

Pakeman, R.J., Hulme, P.D., Torvell, L. & Fisher, J.M. (2003). Rehabilitation of degraded dry heather [Calluna vulgaris (L.) Hull] moorland by controlled sheep grazing. Biological Conservation 114, 389-400.

Palmer, S.C.F. (1997). Prediction of the shoot production of heather under grazing in the uplands of Great Britain. Grass and Forage Science 52, 408-424.

Palmer, S.C.F., Gordon, I.J., Hester, A.J. & Pakeman, R.J. (2004). Introducing spatial grazing impacts into the prediction of moorland vegetation dynamics. Landscape Ecology 19, 817-827.

Palmer, S.C.F. & Hester, A.J. (2000). Predicting spatial variation in heather utilization by sheep and red deer within heather/grass mosaics. Journal of Applied Ecology 37, 616-631.

Palmer, S.C.F., Hester, A.J., Elston, D.A., Gordon, I.J. & Hartley, S.E. (2003). The perils of having tasty neighbours: grazing impacts of large herbivores at vegetation boundaries. Ecology 84, 2877-2890.

Read, J.M., Birch, C.P.D. & Milne, J.A. (2002). HeathMod: a model of the impact of seasonal grazing by sheep on upland heaths dominated by Calluna vulgaris (heather). Biological Conservation 105, 279-292.

Rodwell, J.S. (1991). British Plant Communities Volume 2: Mires and Heaths. Cambridge University Press, Cambridge.

Rodwell, J.S. (1992). British Plant Communities Volume 3: Grasslands and montane communities. Cambridge University press, Cambridge.

Rook, A.J., Dumont, B., Isselstein, J., Osoro, K., WallisDeVries, M.F., Parente, G. & Mills, J. (2004). Matching type of livestock to desired biodiversity outcomes in pastures – a review. Biological Conservation 119, 137-150.

Rushton, S.P., Sanderson, R.A., Wildig, J. & Byrne, J.P. (1996). The effects of grazing management on moorland vegetation: a comparison of farm unit, grazing paddock and plot experiments using a community modelling approach. Aspects of Applied Biology 44, 211-219.

Shepherd, M.J., Anderson, J.M., Bol, R. & Allen, D.K. (2000). Incorporation of 15N from spiked cattle dung pats into soil under two moorland plant communities. Rapid Communications in Mass Spectrometry 14, 1361-1367.

Simpson, I.A., Kirkpatrick, A.H., Scott, L., Gill, P., Hanley, N. & MacDonald, A.J. (1998). Application of a grazing model to predict heather moorland utilization and implications for nature conservation. Journal of Environmental Management 54, 215-231.

Smith, R.S., Charman, D., Rushton, S.P., Sanderson, R.A., Simkin, J.M. & Shiel, R.S. (2003) Vegetation change in an ombrotrophic mire in northern England after excluding sheep. Applied Vegetation Science 6, 261-270.

Terry, A.C., Ashmore, M.R., Power, S.A., Allchin, E.A. & Heil, G.W. (2004). Modelling the impacts of atmospheric nitrogen deposition on Calluna-dominated ecosystems in the UK. Journal of Applied Ecology 41, 897-909.

Thompson, D.B.A., MacDonald, A.J., Marsden, J.H. & Galbraith, C.A. (1995). Upland heather moorland in Great Britain: a review of international importance, vegetation change and some objectives for nature conservation. Biological Conservation 71, 163-178.

Usher, M.B. & Thompson, D.B.A. (1993). Variation in the upland heathlands of Greet Britain: Conservation importance. Biological Conservation 66, 69-81.

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

Vandvik, V., Heegaard, E., Maren, I.E. & Aarrestad, P.A. (2005). Managing heterogeneity: the importance of grazing and environmental variation on post-fire succession in heathlands. Journal of Applied Ecology 42, 139-149.

Virtanen, R., Edwards, G.R. & Crawley, M.J. (2002). Red deer management and vegetation on the Isle of Rum. Journal of Applied Ecology 39, 572-583.

Welch, D. (1985). Studies in the Grazing of Heather Moorland In North-East Scotland. IV. Seed Dispersal and Plant Establishment in Dung. Journal of Applied Ecology 22, 461-472.

Welch, D. (1998). Response of bilberry Vaccinium myrtillus L. stands in the derbyshire peak district to sheep grazing, and implications for moorland conservation. Biological Conservation 83, 155-164.

Welch, D. & Scott, D. (1995). Studies in the grazing of heather moorland in north-east Scotland. VI. 20-year trends in botanical composition. Journal of Applied Ecology 32, 596-611.

Yeo, M.J.M. & Blackstock, T.H. (2002). A vegetation analysis of the pastoral landscapes of upland Wales, UK. Journal of Vegetation Science 13, 803-816.