Sheep on heavily grazed moorland, Exmoor © Paul Glendell/Natural England

Impact of moorland grazing and stocking rates (NEER006)

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Impact of moorland grazing and stocking rates

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Cover photograph

Sheep on heavily grazed moorland, Exmoor © Paul Glendell/Natural England.

Executive summary

Management of the English uplands is complex and achieving good environmental outcomes, while taking into account the needs of owners, stakeholders and other interests is a balancing act. An uplands evidence review has been undertaken in which a number of candidate topics have been considered. These topics were identified through stakeholder input, reflection on areas of advice subject to challenge and looking at what could make a difference on the ground. The five priority topics identified have formed the review programme and will help further the understanding of available evidence to support uplands management.

This topic review focused on a series of questions which were evaluated against scientific evidence. The topic review has also helped identify areas for future research; in the next phase, beyond the review programme, additional relevant information will be considered, for example social and economic factors, current working practices and geographic scale. The evidential conclusions drawn from these additional areas will help inform our future advice and practical management of the uplands on the ground.

Context

The majority of upland semi-natural vegetation is subject to grazing or forage production. Moorland areas are primarily grazed by pure-bred native sheep breeds, which as well as producing lambs for fattening also provides ewes for cross-breeding on upland in-bye land. This in turn provides breeding stock for lowland farms. Thus the moorland sheep flocks underpin the 'stratified' UK sheep industry.

The high nature conservation value of unenclosed upland areas in the UK is recognised through the identification of many of the habitats as Priority habitats in the UK Biodiversity Action Plan (BAP) and inclusion on the list of habitats under the EU Habitats Directive (EU, 1992) Annex 1. Large parts of the English uplands are designated as Special Areas of Conservation (SAC) under the Habitats Directive in recognition of theses habitats, and are Sites of Special Scientific Interest (SSSIs) under domestic legislation.

However, in recent decades overgrazing has impacted on upland landscapes and biodiversity. A major element of agri-environment and other land management schemes is establishing grazing regimes that allow recovery and sustainable management of habitats and which support ecosystem service delivery. Through such schemes the area of SSSI on which overgrazing was a key reason for unfavourable condition has been reduced from 230,000 ha in 2003 to less than 2,500 ha at present.

The Foot and Mouth Disease outbreak of 2001, followed by changes to livestock subsidy payments and a greater emphasis on habitat restoration under agri-environment schemes, has resulted in declines in breeding ewe numbers and beef cattle in upland areas. There are a number of other trends in the structure and practice of upland sheep farms in particular, which are likely to have varying impacts on moorland habitats and ecosystem services.

There remains concern and disagreement about the effects of grazing on the upland landscape and biodiversity, in particular about stocking rates, different livestock types, and the timing and spatial pattern of grazing regimes.

Purpose

The purpose of this report is to comprehensively review the effects of different grazing regimes and stocking rates, including:

- timing of grazing;
- the use of different types of livestock;

- the impacts of livestock management practices and interaction with other land management tools such as burning; and
- the abandonment or absence of grazing on moorland biodiversity and ecosystem service delivery.

Scope

The scope of the review covers the effects of grazing on biodiversity and ecosystem services. The range of outcomes for which research is available varies but generally covers:

- habitat type or mosaics;
- particular plant species or species groups;
- moorland birds;
- invertebrates;
- soils – stability, carbon storage; and
- hydrology.

The review does not consider the effect of the state of our knowledge on Natural England's policy and advice. It does not consider wider social and economic evidence that may influence advice.

Questions addressed by the topic review

The over-arching topic review question is:

What are the effects of grazing regimes and stocking rates on the maintenance and or restoration of moorland biodiversity and on ecosystem service delivery?

The following sub-questions provide a further focus for the review:

a) What is the effect of grazing on moorland biodiversity and other ecosystem services, including timing, frequency and regularity of grazing as well as livestock numbers, and what are the differential effects on integrated moorland ecosystem services?
b) What methods of stocking rate calculation, or setting grazing regimes, consistently provide regimes that maintain or restore moorland biodiversity, and what are the key parameters that calculations should include?
c) What changes have taken place under recent reductions and seasonal changes in sheep grazing, and what is the significance of these changes?
d) Over what timescales can grazing-related change in plant structure and diversity be observed or expected?
e) How is 'under-grazing' defined? What are the effects of low intensity regimes, set to restore small areas of priority habitat within a moorland mosaic, on other parts of the moorland including non-target habitats such as acid grassland?
f) What factors influence the spatial pattern of grazing? How effective are tools such as shepherding and burning in influencing grazing distribution, and how do they interact with stocking rates to achieve improvements in habitat condition and ecosystem services?
g) Do different types of livestock (species and breed), and combinations of livestock, affect moorland habitats differentially?
h) What are the effects of absence or removal of grazing on moorland biodiversity and other ecosystem services?

Process

An initial literature search and call for evidence from stakeholders resulted in 1,192 papers. These were screened by title and abstract for relevance. In total 316 were assessed to be relevant and the full papers were retrieved and checked against the inclusion-exclusion criteria. This resulted in 106 papers being accepted for quality assessment and data extraction (see Section 14). Some additional papers, although not providing quantifiable evidence, were considered relevant as they provided important contextual and background information (see Section 15).

The evidence relating to each sub-question was reviewed and conclusions drawn reflecting the strength of the evidence. In total 116 individual conclusions were derived. There is a high degree of inter-relationship between these sub-questions and recurring themes were drawn out to present a rounded set of conclusions.

Summary of conclusions

A number of key points emerged from the evidence identified under one or more sub-topic, each supported by a number of evidence statements. These key points are presented below, linked to some discussion of aspects of the sub-topics in the context of agri-environment schemes and other work.

The quality of evidence was however found to be variable, with only 21% of the individual conclusions that underpin the above points based on evidence judged as ‘strong’. There is a relative lack of good quality studies on which to base management decisions.

Effects of stocking rate

- There is an association between sheep stocking rates at the landscape scale, and the extent and condition of dwarf-shrub communities.
- Where heather is present its condition, in terms of structure and canopy cover/frequency, can improve through reduced grazing pressure.
- The effects of stocking rates based on estimates of vegetation productivity will vary between sites and years.
- Sheep may provide a degree of *Molinia* control where dead material is reduced through cutting or burning.
- Grazing preferences of livestock vary seasonally.
- Grazing levels affects the structure of moorland food webs.
- Atmospheric nitrogen (N) deposition is likely to influence the effects of grazing.

The current practice within agri-environment schemes in England of setting limits in stocking rates, usually with lower maxima in winter, can have some effect of improving the condition of the heather dominated communities. Removal of a smaller proportion of the annual biomass production of the plant allows height to increase and the canopy to develop in area. There is some evidence that low productivity blanket bog and montane habitats have improved in condition where stocking rates have been reduced to annual averages of around 0.05 LU ha^{-1} yr^{-1} or less, often including off-wintering, and similar rates have allowed some recovery of previously suppressed montane plants in some of England’s rarest and most fragile upland habitats. The effective stocking rate will vary spatially across a mixed grazing unit, so rates that allow recovery of particular habitats may be lower or higher than the overall rate.

However, the evidence suggests that expansion in the area of dwarf-shrub communities is usually limited or slow, as grazing pressure may be concentrated on the margins of dwarf shrubs at the interface with acid grassland communities, and opportunities for establishment from seed in closed grassland swards are limited. Where grazing pressure is low overall, competition from tall grasses often restricts the spread of heathland plants.

Within Higher Level Stewardship there is a degree of tailoring of a stocking limit to the grazing unit, by taking account of the relative proportion of different vegetation types. The output is an overall indicative maximum stocking rate for the unit, which may be adjusted seasonally or monthly. This is still a relatively crude approach, and does not take account of geographic and climatic variation, and other factors that will influence the variation in productivity between sites, such as soils and topography.

The plot-scale controlled grazing studies also show that the level of utilisation and stocking rate that maintains heather cover varies, depending on factors such as the relative proportion of heather-to grass in plots. Other climatic and environmental factors will influence heather growth, and therefore the impacts of a given stocking rate at different sites. There is evidence that the productivity of a particular vegetation type will vary between sites, and between years at the same site (for example, by the different numbers of grazing days required to maintain target utilisation rates or sward heights in different years), suggesting that the impact of a given set stocking rate based on standard figures will differ between sites and years.

However, evidence does point to stocking rates that could form the basis of initial, generic guidance, or a check of whether an observed or calculated stocking rate for a site is likely to have positive results. Understanding of the actual response of the range of vegetation types on a grazing unit requires monitoring, designed to collect information on the utilisation of key components of the vegetation and the distribution of grazing impacts. This needs to be done in a way that informs the review and adjustment of grazing regimes to ensure site objectives are met (ie adaptive management).

Effects of recent changes in livestock numbers on moorland

- Expansion of dwarf shrub habitat can be slow or lacking under ESA stocking rates.
- Change in vegetation community type and broad character through grazing reduction or removal may take several decades.
- Low productivity or climatically stressed habitats may respond relatively quickly to changes in grazing pressure.

Whilst the detrimental effects of increased sheep grazing on moorland over the second half of the 20th century have been well documented there is limited evidence to indicate large-scale changes in moorland vegetation communities arising from recent reductions in grazing. However evidence is presented in this review of improvements in habitat condition and positive responses in important plant populations over relatively short timescales. Concerns are expressed by the farming community of the effects of under-grazing, for example, of the spread of bracken. This was not supported by the national Countryside Survey (Countryside Survey, 2009), which detected an increase of 15% in the area of dwarf shrub heath between 1998 and 2007. Whilst not statistically significant and reflecting some changes in analysis methods, the greatest increase was detected in the upland zone, mainly at the expense of acid grassland. Other than this, the area of mountain, moor and heath habitats showed very little change.

Within the dwarf shrub heath broad habitat the main change detected in the upland zone was an increase in the ratio of grasses to forbs, following a decrease in this ratio over 1990-1998. Species that decreased in frequency tend to be shorter grasses and sedges, with increases in taller grasses and rushes. The dwarf shrub cowberry (*Vaccinium vitis-idaea*) was however among the species with the greatest increase in frequency over this time. There was a significant increase in measures of competitive species in the bog and upland acid grassland broad habitats between 1998 and 2007, and a decrease in stress-tolerant species. Overall cover of bracken and common gorse decreased significantly, and western gorse and hawthorn increased.

The evidence suggests that between 1998 and 2007 there was little indication of large-scale changes in the character of moorland that might result from reductions in grazing pressure. However, there is an indication from the Countryside Survey species results that taller, more competitive plants are increasing in frequency, which may be related to grazing reductions, and is consistent with many of the findings from grazing reduction and exclusion studies reviewed here.

Spatial factors

- The overall impact of a given stocking rate is influenced by the size and distribution of patches of preferred grazing.
- Grazing livestock do not range evenly over a moorland grazing unit.
- Livestock influence vegetation change by mechanisms in addition to grazing defoliation.

In reality, as evidenced here, livestock do not range evenly over an area of moorland and the distribution of sheep in particular is likely to be heavily influenced by the location of preferred

vegetation. In addition, many hill sheep management systems utilize sheep home-ranging behaviour, in maintaining “hefts” or distinct flock grazing areas. The strength and pattern of home-ranging may vary between sheep breeds.

Management hefts are likely to be influenced to some extent by the location of the farm and moorland access points, rather than solely the distribution of vegetation types, although there will be an interaction due to the grazing preferences displayed by sheep. The hefting system, or homeranging behaviour, may have a role in spreading grazing around on shared grazings such as common land.

A likely barrier to the achievement of ecosystem service outcomes, and possibly for biodiversity objectives in particular, is this variability in grazing pressure across a diverse grazing unit. The grazing patterns that result from sheep ranging behaviour and grazing preferences, management practices and topography are unlikely to match the conservation grazing requirements of different habitats and species. A reduction in sheep numbers, resulting either from conservation schemes or changes to farm enterprise structure, will not necessarily deliver these varying grazing requirements fully. A challenge for conservation advisers and land mangers is to better match livestock grazing patterns to the requirements of different habitats.

There is strong evidence that heather utilisation by livestock in general, and sheep in particular, is influenced by the choice of grazing and resting areas within the home range. Impact on heather and other dwarf shrubs is greatest in a narrow zone around grass patches, and the size and distribution of grass patches, along with the proportion of preferred grass species in patches, greatly influences the overall impact of grazing and its effects.

On many English types of moorland there is often a grass-dominated zone on the margins of expanses of dwarf-shrub dominated vegetation, particularly where management of heather for grouse is practiced. Whilst the zone of high heather utilisation may be relatively small in terms of the overall area of heather it is likely to result in contraction of the heather area over time, at a faster rate when livestock numbers are high. There is evidence that sheep are more likely to graze on young regenerating heather than older heather, which may reduce the concentration of grazing pressure in the grass to heather transitions.

The evidence for sheep to select grass patches of a particular size class is inconsistent, with evidence from one study and suggestions from others that sheep preferentially graze larger patches, and evidence from two related studies that sheep select small patches. This may reflect different learning and experience of the grazing animals, and highlights the need to understand the characteristics of livestock in setting grazing regimes.

The role of cattle

- Grazing pressure and livestock type influences the balance of preferred to less preferred graminoid species.
- Grazing selectivity and choice varies between livestock species and there may be greater inter-breed variation in sheep than cattle.

- Summer cattle grazing is almost as effective as grazing exclusion in facilitating heather establishment from seed.

There is evidence from heather restoration studies that interventions that cause disturbance and create bare ground can aid the establishment of heather. Whilst it is impractical to implement this on a large scale, there may be a role for cattle grazing on moorland in providing localised disturbance, which could aid dwarf-shrub establishment if sheep grazing pressure is low or absent. Cattle have also been shown to graze less selectively than sheep, and may graze grass species such as *Nardus stricta*, usually avoided by sheep. In the medium term this might increase the proportion of preferred grasses in the sward and improve the quality of semi-natural grassland for light/moderate sheep and mixed grazing.

Cattle grazing needs careful management, however, as it can have detrimental impacts on vegetation through trampling and dunging, including damage to woody stems of heather. Evidence indicates that cattle will tend to spend most of their time on more fertile vegetation and around water supplies, and are unlikely to range evenly over a grazing unit. This may serve to reduce grazing on areas that sheep would be more likely to graze, where cattle are the sole grazers, or it may mean that target vegetation is not grazed to the degree that is required. Cattle grazing patterns can encourage sward heterogeneity, with potential to influence the abundance and diversity of different taxa.

Evidence suggests that diets selected by different breed types of cattle are similar, and that breed influence on diet is much less than between breeds of sheep. This may in theory increase the options of farmers in grazing semi-natural areas, utilising more commercially oriented breeds. It is likely however that the condition and productivity of such animals will be compromised where semi-natural moorland vegetation is a significant part of their diet, and that native hardy breeds are better suited to these environments.

Grazing removal and low intensity regimes

- Low intensity mixed grazing regimes can have biodiversity benefits.
- Moderate grazing can maintain plant species-diversity.
- Periods of summer grazing reduction or removal can benefit populations of key plant species.
- Relatively light grazing by sheep can affect the vegetation composition and condition of blanket bog.

There is evidence that periods of sheep removal can benefit not only heather establishment and improvement in condition, but can allow some recovery of heavily suppressed species which have few flowering opportunities, even under light sheep grazing. It is likely that prolonged grazing exclusion could be detrimental in all but the very lowest productivity or most climatically suppressed habitats, as competitive species increase and gaps for colonisation by less competitive species are lost. Targeted short or medium-term grazing exclusion could however be used in managing rare or restricted habitats and populations.

Similarly, relaxation or removal of grazing has been shown to allow recovery or increases in population of invertebrates and some moorland or upland birds, notably black grouse, but as swards become dense the effects are reversed as mobility and access to prey is compromised. There is evidence that tall grass that might be considered a sign of under-grazing can be important for moth diversity, and have increased insect abundance overall. However, studies also show that some moth species of conservation importance are associated with more heavily grazed situations, and skylarks are associated with short vegetation. Other species require tussocky vegetation, or contrasting structure at the foraging or territory scale.

There is some evidence that lightly grazed or ungrazed moorland vegetation is associated with greater soil microbial diversity, but reduced biomass compared to moderately grazed areas. Lack of grazing has been shown to increase carbon storage in above ground vegetation and the litter layer and root zone, but reduce the rate of assimilation of carbon dioxide (CO_2) compared to grazed situations.

It would seem that there is a role for targeted grazing exclusion or removal for allowing habitat or population recovery or providing habitat mosaics for different species. For restoration and recovery clear site-specific targets need to be set, that inform criteria for how and when grazing can be reintroduced.

Under-grazing

The review did not identify any studies that specifically attempted to quantify when moorland might be considered under-grazed. This is not entirely unexpected as the concept of under-grazing is largely a value judgement and dependant on the objectives set for a site or feature. There are however pointers from a number of studies to various scenarios that might be considered under-grazed in terms of the objectives set. A common understanding of what constitutes under-grazing for different outcomes, including livestock management, is required and how this might look in different habitats.

Grazing impacts on soils, water and carbon

- There is a link between grazing and soil erosion and loss.
- The impact of grazing on carbon sequestration and storage within moorland is variable, as it effects the relative contribution of different mechanisms.
- Grazing may have little effect on water quality, at least at relatively low stocking rates.

A significant grazing impact on ecosystem services has been the creation of bare ground and the soil erosion that may follow. This affects the moorland resource, its productivity and the potential for habitat restoration, but also results in siltation of watercourses and reservoirs. Further evidence is provided in the soil erosion studies reviewed here, of the need to limit grazing pressure, and suggests that stocking rates similar to those likely to improve habitat condition can also aid recolonisation of erosion scars. However, since erosion is often initiated on steep ground and where preferred grasses are found, the effective grazing pressure on these areas may be higher than the average for the grazing unit, and requires monitoring and consideration of the spatial distribution of grazing pressure.

Evidence was found that grazing reduced carbon storage in above ground vegetation and the upper soil horizons compared to ungrazed plots. There was no evidence of a consistent effect of grazing on carbon sequestration in deeper soil horizons in moorland peat and organic mineral soils. There was no evidence that grazing affected carbon accumulation in peat, but grazing may positively influence peat forming conditions through promoting a shallower water table.

There is no published evidence of grazing effects on water quality.

Grazing does appear to influence soil microbial communities, in term of biomass and the relative contribution of bacteria and fungi, which in turn affects soil processes such as the rate and efficiency of nutrient cycling. Grazing removal results in reduced microbial biomass and nutrient (carbon and nitrogen) cycling, due possibly to reduced dung inputs and changes in the character of plant litter. There is evidence that microbial biomass and associated nutrient cycling may be optimal at moderate grazing levels. There is also evidence of a greater proportion of fungi in the soil biota of less intensively grazed and ungrazed sites.

The evidence suggests that “moderate” and “variable” (both spatially and temporally) levels of grazing are the most appropriate for delivery of many ecosystem services (including those related to soil carbon and biodiversity), though not necessarily those related to animal production.

Research recommendations and gaps

- A better understanding of the grazing and ranging behaviour of the common hill sheep breeds in England is needed, as the few studies that exist are based on Scottish blackface sheep. Possible changes arising from changes in the stratified sheep industry, including the trend for cross-breeds in particular, need to be evaluated in terms of what they may mean for grazing levels and patterns on moorland.
- There is a need to develop a more meaningful Livestock Unit (LU) system which takes into account not only the animals‟ nutritional requirements but the grazing choices that are made by different species, breed types and classes of stock when fulfilling these.
- There is a need to explore how information on the spatial distribution of vegetation types in a grazing unit should be used more effectively in setting stocking levels. This could include the examination of the potential role of hefting, as hefting will affect how animals will interact with the pattern of vegetation and its utilisation.
- Further research is required into techniques that can be used to influence the spatial distribution and feeding choices of sheep and cattle, including the provision of water and the use of supplementary feeding. Cutting or burning areas of less preferred vegetation and standing dead material can improve the attractiveness of underutilised areas, and the role of these techniques could be explored further.
- There is a need to develop a common understanding of what constitutes true under-grazing for different outcomes, and how this might look in different habitats.
- The interaction of grazing and heather beetle damage should be evaluated.
- There is a need for better evidence on grazing impacts and achievements – including assessments of the distribution of grazing pressure as well as the response of habitats or species. Methods need to be improved to ensure that ecologically meaningful measurements are made, but that these can be done quickly and efficiently.
- More evidence is needed on carbon budgets in different grazing/soil combinations. As management moves towards considering ecological services in the round, then understanding the trade-offs between different services, such as carbon sequestration and livestock production will be necessary.
- More evidence is needed on the impact of grazing on water quality in different soils.

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1 Introduction

Background to the review

1.1 In March 2011 Defra published the Government's review of uplands policy which sets out a range of actions the Government, led by Defra, will take in partnership with others in the public, private and voluntary sectors to help secure a sustainable future for the English uplands. The actions in the Uplands Policy Review sit under four main themes:

- Supporting England's hill farmers.
- Delivering public goods from upland environments (including biodiversity).
- Supporting sustainable upland communities.
- Driving and monitoring change.

1.2 Natural England has a specific role in helping deliver the Uplands Policy Review; in particular through our research and evidence based advice, our delivery of agri-environment schemes, and our partnership work with the hill farming and moorland management sector and rural communities to deliver a wide range of public goods and environmental benefits. Our role in the uplands is also shaped by our broader role in the delivery of the Government's Natural Environment White Paper and Biodiversity 2020 aspirations that focus on the enhancement and protection of ecosystem services and the natural environment, including improving the condition of England's Sites of Special Scientific Interest (SSSIs). Biodiversity 2020 targets for SSSIs are to achieve 50% in favourable condition as defined by Common Standards Monitoring for upland habitats and 95% in favourable recovering condition by 2020.

1.3 For these reasons it is important that our advice and decisions are based on sound evidence, and that our evidence processes are transparent and robust.

The need for the review programme

1.4 The English Uplands are extensive and include a range of habitats, species, and land management practices. It is widely recognised that they provide provisioning, regulatory, and cultural ecosystem services.

1.5 In seeking to improve the condition of habitats and landscapes and to secure the benefits and services they provide, the uplands present a number of environmental conservation and land management challenges. This is particularly the case in understanding the effects of land management operations on upland biodiversity.

1.6 The review programme seeks to draw together the best available on the effects of land management activities on upland biodiversity and ecosystem services, focussing on unenclosed moorland habitats and extensively managed semi-natural areas. In doing so it provides a basis for the development of advice and decisions on future management of the uplands.

The nature of the evidence

1.7 Over several decades a body of evidence has accumulated exploring the effects of different types of land management interventions on a range of upland ecosystem services, habitats and species. There is a wide variety of study types, for example, controlled grazing trials, correlative and observational studies, some of which have taken advantage of opportunities for natural experiments. Randomised control trials, which represent perhaps the most robust experimental approach, are reasonably well represented in the literature but vary in the degree of replication and whether they are fully or partially randomised. There are many methodological differences within this literature, notably the lack of consistency between measurement methods and different outcomes measures. There are also limitations in the degree to which small plots and enclosures and small livestock numbers reflect the real-world situation and controlled treatment and observational studies cannot fully take account of the range of factors that influence natural systems. Overall, the evidence provides a basis from which conclusions about intervention effects and research needs can be developed.

1.8 It is worth noting a number of significant challenges associated with undertaking a review of the evidence on upland management interventions. Firstly, the search strategy needs to be broad enough to capture studies from non-traditional sources including sources and journals not indexed in environmental databases, and work that may be in the 'grey' literature (such as reports or case studies). Secondly, studies may present un-validated measures that can be difficult to equate to effects on biodiversity or ecosystem services. Finally, the wide range of study types, for example, post-grazing only measures or uncontrolled pre and post-grazing studies, increase the risk of erroneous conclusions.

Scope of the review programme

1.9 The uplands are a broad biotope encompassing a variety of habitat, species and ecosystem services, and are subject to a variety of land management interventions. For the purposes of this review, the uplands are defined as that land designated as Less Favoured Area (LFA) and moorland is the land within the LFA, and within the Moorland Line (ML). The Natural England review of upland biodiversity and ecosystem evidence focuses on five topics where there are significant challenges:

- Impacts of tracks and vehicle use on soil structure and hydrology and their impacts on biodiversity.
- Feasibility of restoring degraded blanket bog including areas such as drainage, vegetation cover (peat forming species), and climate change.
- Impacts of managed burning on peatland biodiversity and ecosystem services.
- Appropriate management regimes for sustaining biodiversity in upland hay meadows.
- The Impacts of grazing regimes and stocking rates on moorland biodiversity and ecosystem services

1.10 This topic report presents the findings from the review of the impacts of moorland grazing regimes and stocking rates.

1.11 Consideration of other relevant information, such as social and economic factors, is an important part of the process of developing Natural England's advice, but is not part of this review. Climate scenarios are also excluded from the review.

Review topic: Impact of moorland grazing and stocking rates – background and context

The historical context

1.12 The majority of upland semi-natural vegetation is subject to grazing, or forage production. Moorland areas are primarily grazed by pure-bred native sheep breeds, which as well as producing lambs for fattening also provides ewes for cross-breeding on upland in-bye land, which in turn provides breeding stock for lowland farms. Thus the moorland sheep flocks underpin the 'stratified' UK sheep industry.

1.13 However, in recent decades overgrazing has had an impact on upland landscapes and biodiversity. A major element of agri-environment and other land management schemes is establishing grazing regimes that allow recovery and sustainable management of habitats and which support ecosystem service delivery. Through such schemes the area of SSSI on which overgrazing was a key reason for unfavourable condition has been reduced from 230,000 ha in 2003 to less than 2,500 ha at present.

1.14 The high nature conservation value of unenclosed upland areas in the UK is recognised through the identification of many of the habitats present as Priority habitats in the UK Biodiversity Action Plan (BAP) and inclusion on the Annex 1 list of habitats under the EU Habitats Directive (EU, 1992). Large parts of the English uplands are designated as Special Areas of Conservation (SAC) under the Habitats Directive in recognition of theses habitats, and are SSSIs under domestic legislation. Many areas are important for their breeding bird populations and carry the additional designation of Special Protection Area (SPA) under the EU Birds Directive (EU, 2009).

1.15 Changes in the characteristic flora of upland habitats, and in particular the loss of heather (*Calluna vulgaris*)-dominated moorland to grass-dominated vegetation, has been attributed to increases in sheep numbers, largely since the 1940's, encouraged in part by headage-based livestock subsidy payments under Common Agricultural Policy (CAP) provisions. Whilst a number of experimental studies on the effects of grazing pressure and timing on heather condition are reviewed here, the evidence for large-scale effects of changes in sheep grazing pressure on moorland vegetation comes from a number of correlative studies summarised in Thompson *et al.* (1995). Changes in heather cover co-incident with increases in sheep numbers from agricultural census records are documented, for example, by Anderson & Yalden (1981) for an area of the Peak District and Felton & Marsden (1990) for Cumbria. A sample survey of 158 moorland grazing units in England and Wales by Bardgett *et al.* (1995) indicated decreasing heather cover and condition above an average stocking rate of 2 ewes ha^{-1}.

1.16 Fuller and Gough (1999) demonstrated trends in sheep numbers based on June Agricultural census data for different parts of the UK, and different areas of England. The data showed consistent increases in breeding ewe and total sheep numbers between 1950 and 1990 encouraged in part by headage based subsidy systems allied to technological changes, the overall increase for England being 142%. Fuller and Gough went on to explore the implications for upland bird populations, but pointed out the lack of detailed monitoring studies at that time.

The policy response to environmental concerns

1.17 Concerns over heather loss led to the introduction of agri-environment schemes and other environmental measures in the late 1980's. Environmentally Sensitive Areas (ESAs) were the most widespread scheme in upland areas and generally incorporated two tiers of management, tier 1 aimed at maintenance of moorland communities, and tier 2, aimed at restoration. As a voluntary scheme, the uptake of the less restrictive tier 1 was significantly greater than tier 2 (for example, Ecoscope, 2000). The typical prescription stocking rates applied in each tier are shown in Table 1, and were blanket rates applied to the whole grazing unit irrespective of habitat type and condition. It should be noted that these rates were maxima allowed for a given period. In reality they represent the stocking rate typically applied, with little voluntary reduction below these maxima. Stocking rates are expressed as Livestock Units (LU) per hectare.

1.18 Moorland grazing units in ESAs were monitored in some detail during the 1990s. The findings, summarised, for example, by Ecoscope (2000), Natural England (2009) and Nisbet & Glaves (2010), show that heather moorland extent and condition was generally maintained. Examples of enhancement were fewer and usually occurred under tier 2, with the associated lower stocking rates and reduced winter grazing. A summary of monitoring findings from all heather moorland ESAs is given in Appendix 1.

Table 1 Typical maximum ESA stocking rates in summer and winter, and range of maxima across upland ESAs, expressed as Livestock Units (LU) per hectare

	Maximum stocking rate (LU ha^{-1})			
	Typical summer	Range summer	Typical winter	Range winter
ESA Tier 1	0.225	0.15-0.36	0.17	0.12-0.235
ESA Tier 2	0.1	0.1-0.17	0	0-0.08

Within ESAs an upland ewe plus followers (lambs and replacements) was taken to be 0.15 LU. The summer tier 1 rate therefore equates to 1.5 ewes plus followers per ha. NOTE: these figures assume the European Commission LU equivalents; see Table C, Appendix 3.

1.19 Within the Countryside Stewardship Scheme (CSS), available outside of ESAs, upland moorland options were available from 1999. Whilst maximum stocking rates applied under the options were similar to those of ESAs, they were implemented with a greater degree of flexibility. In restoration situations, for example, supplementary payment could be made for additional ewe removal, including complete removal during winter.

1.20 Cross-compliance measures to limit overgrazing were attached to LFA and livestock scheme payments from 1992, and are now a requirement of the Single Payment Scheme (SPS) as a Good Agricultural and Environmental Condition (GAEC) measure. Overgrazing assessments were originally based on the degree and extent of damage to dwarf shrub, but following a review of overgrazing policy in 2003 a more holistic approach inclusive of the main moorland vegetation types was developed (Glaves 2003). Parallel to this, stocking rates were developed for each of the main moorland vegetation types, based on data from research of vegetation productivity (for example, Milne *et al.* 2002), and sustainable utilisation (Armstrong, 1990) and livestock dietary requirements. This allowed an overall rate to be calculated for a grazing unit, based on the proportions of each vegetation type present.

1.21 More recently under the Environmental Stewardship Scheme, which replaced ESAs and CSS from 2005, and the Higher Level Stewardship (HLS) element in particular, farmers have been encouraged to enter moorland into restoration options, generally with lower stocking rates than specified under original ESA agreement. From the various measures discussed above, the typical mean annual stocking rates and ranges can be compared, with generalised outcomes. The habitat-specific stocking rates applied under HLS and cross-compliance measures are presented in Appendix 2.

Table 2 Typical stocking rates (LU ha^{-1}) applied under each policy measure, expressed as mean and range of annual average rates, and summer and winter maxima, with generalised outcomes

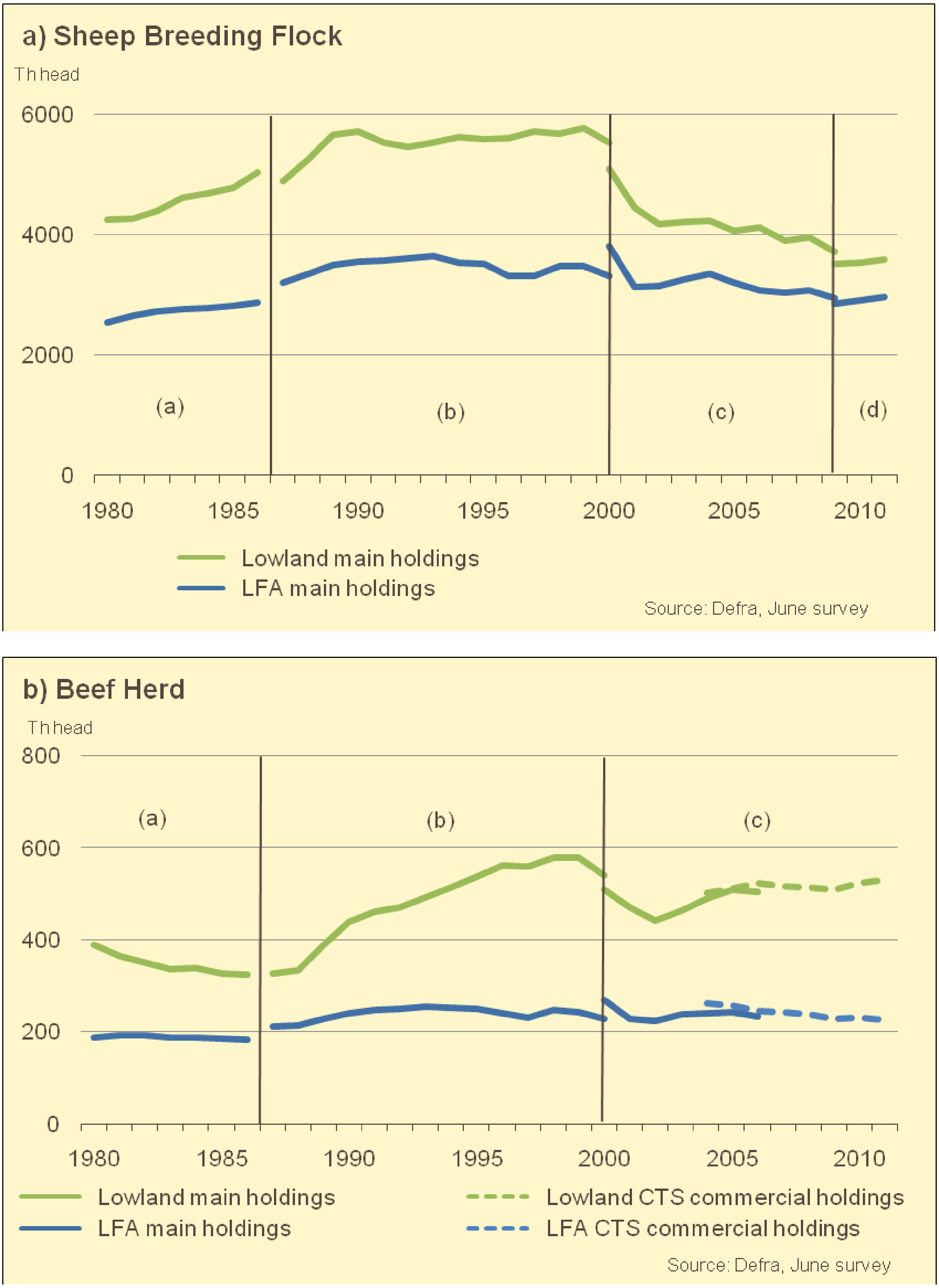
Measure	Typical mean annual stocking rate	Range of mean annual rates	Typical summer max	Typical winter max	Outcomes
Environmental Cross-Compliance	0.24	0.12-0.3	0.26	0.18	Reduction in direct measures of grazing, including significant reduction in Grazing Index. Little measurable improvements in vegetation condition.
Classic scheme maintenance	0.2	0.13-0.21	0.225	0.17	Often maintained heather cover, but little improvement in condition. On-going deterioration in some cases.
Classic scheme restoration	0.09	0.06-0.13	0.1	0.07 (0)	Some recovery of dwarf shrub, including increases in cover.
Higher Level Stewardship	0.1	0.02-0.3	0.13	0.08	

1.22 The pattern of mean and maximum stocking rates applied under different policy measures shows a general decrease as the objectives move towards habitat restoration. HLS is less prescriptive than precursor schemes and the moorland options incorporate a greater degree of flexibility to generate site-specific grazing regimes. It is notable that the typical mean and maximum rates are very similar to those within restoration options of classic schemes, under which habitat restoration was more likely to be achieved. The range of annual mean rates is however much wider, reflecting the flexibility of the scheme and, at least in part, a wider range of features and objectives, and the different management responses required to address them.

1.23 The Foot and Mouth Disease (FMD) outbreak of 2001 resulted in a sharp decline in ewe numbers, and led to long-term changes as many businesses were restructured and did not re-stock to previous levels. This greater emphasis on habitat restoration under current schemes, along with decoupling of subsidy payments from livestock numbers in 2005 and other long-term social trends in hill-farming communities has led to further declines in livestock numbers in the uplands (Clothier & Finch, 2010; Silcock *et al.* 2012). Data from the Defra Agricultural Census reported in these sources suggest there has been a decrease of 0.5% in beef cow numbers in the English LFA over the period 2000-2010, but this masks a reduction of 17.1% in the Severely Disadvantaged Areas (SDA) which includes the majority of moorland area. The reduction in breeding ewes in the LFA over this period was 12%, with 23% in the SDA.

1.24 Trends in breeding sheep and beef cattle numbers on lowland holdings and the LFA in England, from 1980 to 2012, are shown in Figure 1. Breeding ewe numbers in 2010 were at a similar level to that of the early 1980s (Clothier & Finch, 2010), having undergone increases between 1980 and the mid 1990s. Change in livestock numbers and their effects have not been uniform across moorland, with reductions in the number of whole flocks as well as in flock size. The Pastoral Commoning Partnership (2008) reported a decrease in the number of active graziers on upland commons over the previous 20 years. Clothier & Finch (2010) and Silcock *et al.* (2012) also report differences in the magnitude of change in livestock numbers between regions. The latter report also highlights a number of other recent and on-going changes to grazing regimes in the LFA including: a move away from traditional and hill breeds of cattle and sheep with increased cross-breeding of sheep; increased off-wintering of sheep and a later start to summer grazing; reduced stock management including hefting and shepherding on moorland; and less supplementary feeding on moorland. The reasons behind these changes are complex and impacts on moorland may be positive or negative depending on the magnitude of change and site characteristics. At least some of these trends are influenced by Agri-environment schemes and designated site objectives.

1.25 As a result of these changing drivers and trends over time the studies reviewed here have been undertaken for a range of different purposes. Many earlier studies were aimed at maintaining a range of hill forage for livestock production, and understanding the implications of grazing for optimal forage production and nutrition. More recent studies have sought to identify maintenance and restoration regimes for different habitats, to contribute to conservation policy and objectives for biodiversity and ecosystem service provision. The effect of complete grazing removal over different timescales has also been a common element of the research.



(a)1975 definition of LFA before widening to include Disadvantaged Areas, excludes minor holdings; (b) Current LFA, excluding minor holdings; (c) 1n 2006 the method of assigning LFA markers to holdings was revised and retrospectively applied from June 2000. All holdings; (d) Commercial holdings only.

Figure 1 Change in a) sheep breeding flock and b) beef herd in the English lowlands and LFA since 1980 - 2012

Physiological and behavioural drivers of livestock grazing

1.26 This review focuses on the impacts and outcomes of grazing on environmental attributes. There is a large body of literature that reports on the underpinning physiological mechanisms of grazing and the behavioural and nutritional aspects that drive animal grazing choices. Many such sources, whilst not fully considered for the purposes of this review, provide important contextual information, and a brief overview is presented here.

1.27 The grazing behaviour and choices made by a grazing animal is a direct effect of the qualitative or quantitative limitations on the food items available. The relationship between body size and metabolic requirement is strong (for example, Illius & Gordon, 1987), and this has a fundamental effect on the foraging strategy and the degree of selectivity and scale at which selectivity takes place. (Jarman and Sinclair, 1979; Schwartz and Ellis, 1981). Additional factors such as age, physiological status (for example, pregnant, lactating), digestive physiology (ruminant, hind-gut fermenter) and environmental conditions may further influence the degree of selectivity exhibited.

1.28 Depending on the choices made, the composition of the diet consumed may be substantially different to the proportions of various species or plant parts present within a particular community or sward. However, the scope for selection will depend on the heterogeneity of the vegetation the animal is feeding from and the spatial distribution of different plant components.

1.29 Several studies or reviews summarise these physiological and behavioural drivers, and their interaction with, and impact on, vegetation attributes. Reviews such as that by Milne (1994), compare the grazing attributes of sheep and cattle, and suggest that different livestock species can be grazed together to achieve improved production and management objectives. Rook & Tallowin (2003) consider the mechanisms by which grazing animals create heterogeneity in grazed swards, and how this might benefit biodiversity. Studies which investigate experimentally aspects of animal behaviour or grazing selectivity that are more clearly related to habitat (for example, Grant *et al.* 1985) or other biodiversity or ecosystem service effects are included in the current evidence review.

What is considered in this topic review?

1.30 This topic review considers the effects of different grazing regimes and stocking rates, including:

- timing of grazing;
- the use of different types of livestock;
- the impacts of livestock management practices and interaction with other land management tools such as burning; and
- the abandonment or absence of grazing on moorland biodiversity and ecosystem service delivery.

1.31 Moorlands are areas of open semi-natural vegetation generally occurring above the limit of agricultural enclosure and dominated by native self-sown or self-propagated plant species. The predominant habitats found are wet and dry dwarf-shrub heath and blanket bog, upland acid and calcareous grasslands, various types of fens and mires, bracken, scrub, moss-heaths found on the very highest tops and tall herb vegetation found on cliff ledges. The mountains, moorlands and heaths broad habitat is recognised in the National Ecosystem Assessment (2011) as delivering a wide range of provisioning, regulating and cultural services. The ecosystem services considered in this topic review are limited to those that are likely to have a direct link to the quality of moorland habitats and the processes that operate within them. Evidence is therefore considered for grazing effects on the regulating services of climate regulation (carbon storage), flood regulation, water quality and erosion control, and the provisioning services of water supply and quality. The largest body of evidence inevitably relates to the effects of grazing on vegetation and therefore directly or by inference to biodiversity.

1.32 The National Ecosystem Assessment recognises a range of other services from moorland habitats including food and fibre production and the cultural services of recreation, spiritual and aesthetic values and recreation, but these are outside the scope of the current review. Since livestock grazing is the subject of the review, the intrinsic link to the provisioning services of food and fibre production has to be acknowledged.

The over-arching topic review question

1.33 **What are the effects of grazing regimes and stocking rates on the maintenance and or restoration of moorland biodiversity and on ecosystem service delivery?**

The following sub-questions were the focus of review:

a) What is the effect of grazing on moorland biodiversity and other ecosystem services, including timing, frequency and regularity of grazing as well as livestock numbers, and what are the differential effects on integrated moorland ecosystem services?
b) What methods of stocking rate calculation, or setting grazing regimes, consistently provide regimes that maintain or restore moorland biodiversity, and what are the key parameters that calculations should include?
c) What changes have taken place under recent reductions and seasonal changes in sheep grazing, and what is the significance of these changes?
d) Over what timescales can grazing-related change in plant structure and diversity be observed or expected?
e) How is ‘under-grazing’ defined? What are the effects of low intensity regimes, set to restore small areas of priority habitat within a moorland mosaic, on other parts of the moorland including non-target habitats such as acid grassland?
f) What factors influence the spatial pattern of grazing? How effective are tools such as shepherding and burning in influencing grazing distribution, and how do they interact with stocking rates to achieve improvements in habitat condition and ecosystem services?
g) Do different types of livestock (species and breed), and combinations of livestock, affect moorland habitats differentially?
h) What are the effects of absence or removal of grazing on moorland biodiversity and other ecosystem services?

Comparator

1.34 The sub-questions generally assume that the desired outcomes of a sustainable grazing regime are moorland habitats exhibiting the characteristic flora of areas of high nature conservation value (see Historical context above). The comparators, reflecting sub-optimal conditions, for the questions in this review are therefore usually either:

1) Upland heathland or blanket bog communities where the heath component is in a suppressed and fragmented state; or
2) Graminoid-dominated moorland vegetation on deep and shallow peat and mineral soils, through heavy selective grazing of dwarf shrub, herbs and favoured grasses, or avoidance of less favoured graminoids.

Habitat and species terminology

1.35 The accepted convention in describing vegetation communities is to follow the National Vegetation Classification (NVC). Volumes 2 and 3 (Mires and Heath, and Grasslands and Montane Communities respectively; Rodwell, 1991, 1992) are the most relevant to this report. Although NVC communities are named in a few places, many studies used in the review do not refer to the NVC, either because they pre-date its publication, or more general terminology is applied. It is common, for example, to refer to vegetation in terms of the dominant grass or dwarf shrub species, usually by the taxonomic genus name, where there is little ambiguity about the species referred to in a UK context. Therefore *Molinia caerulea* (purple moor-grass), for example, is usually presented as *Molinia*.

1.36 There is often a clear relationship between a named dominant, and a NVC community, *Nardus* grassland, for example, generally refers to U5 *Nardus stricta- Galium saxatile* grassland and *Agrostis-Festuca* to U4 *Festuca ovina-Agrostis capillaris-Galium saxatile* grassland. In other cases, however, the relationship is not so clear - *Calluna* moorland can encompass a number of dry and wet heath NVC communities. Other commonly used broad habitat terms, such as blanket bog and upland heathland, are also used in the report. A degree of consistency has been attempted, without attempting to standardise all descriptions to the NVC.

2 Methods

2.1 This chapter briefly sets out how this topic review was undertaken following the approach described *Natural England Evidence Reviews: guidance on the development process and methods* (Stone, 2013).

Evidence search

2.2 Literature searches were conducted using the terms listed below. References were downloaded, or manually added if necessary, into a reference manager database (EndNote Web) and duplicates removed. References were also identified through contact with key international and national experts and lead organisations. In addition, there was an open call to interested stakeholders to submit evidence material for consideration as part of the review.

Search terms

2.3 The following search terms were used. Searches were made on the individual sub-topics, but inevitably there was a high degree of overlap in search terms used, and some searches were amalgamated to reduce duplication. The keywords used fairly generically are presented, along with those that were applied to specific sub-topic searches.

Generic search terms

2.4 For population (ie habitat or species):

Moorland vegetation, Biodiversity, Heathland, Ecosystem Services, Upland Heathland, Heather moorland, Blanket Bog, Mire, Wet heath, Upland Calcareous grassland, Moorland mosaic, Upland habitats, Carbon storage, Sequestration, Water supply, Water flow.

2.5 For intervention:

Grazing, grazing pressure, timing of grazing, Stocking rate, Grazing regime, Stocking level, Restoration , Maintenance, Sustainable grazing, Winter grazing, Summer grazing, Stocking calendar, Selective grazing, Grazing pattern, Spatial pattern, Biomass utilisation, Sustainable utilisation.

2.6 Comparison/control:

Acid grassland, Suppressed heathland, No change, Heavy grazing, Overgrazing, Uneven grazing, Fragmentation, Mat grass, *Nardus*, Purple moor-grass, *Molinia*, Unpalatable, Trampling, Erosion, Rank grassland, Unfavourable condition, Runoff, Deterioration.

2.7 Outcomes (or effect):

Habitat condition, Favourable condition, Species composition, Vegetation structure.

2.8 Community:

Species diversity, Carbon storage, Water retention, Moorland condition.

Additional search terms

2.9 Setting grazing regimes:

Stocking rate calculation, Off-take, Grazing index, Vegetation productivity, Sustainable stocking rates, Sustainable utilisation, Sustainable off-take.

2.10 Recent change/timescales:

Plant structure, Species diversity, Spatial distribution of grazing, Long-term study, Monitoring, No change, Detectable change, Improve condition, Tall vegetation, rank vegetation.

2.11 Spatial influence:

Hefting, Burning pattern, Feed blocks, Grazing manipulation, Shepherding, Grazing pattern, Spatial grazing.

2.12 Undergrazing:

Undergrazing, Tall vegetation, Rank vegetation, Scrub, Polarisation, Grazing avoidance.

Search strategy

2.13 The following databases were searched:

Web of Knowledge, Wiley Blackwell, Science Direct, Copac, Scirus, Envirobase and Natural England's online library catalogue (Olib).

2.14 Publication searches were undertaken on:

Countryside Council for Wales, Scottish Natural Heritage, The James Hutton Institute (formerly The Macaulay Land Use Research Institute), and the Institute of Biological Environmental and Rural Sciences (IBERS) of Aberystwyth University, which incorporates the publications archive of the Institute of Grassland and Environmental Research (IGER).

2.15 The open call for evidence attracted 105 submissions (individual pieces of evidence) from the following stakeholders: RSPB, National Trust in the West Midlands, the Forestry Commission, the Federation of Yorkshire Commoners and Moorland Graziers, the Federation of Cumbrian Commoners, the Foundation for Common Land, Jeremy Roberts, independent botanist, David Pardoe, A E Peart, and Dr Robert Evans.

Selection of studies for inclusion

2.16 The search strategy resulted in 1,192 titles. These were screened by title and abstract for relevance. In total 316 were assessed to be relevant and the full papers were retrieved and checked against the inclusion-exclusion criteria. Where any uncertainty existed the full paper was assessed by a second reviewer. 106 papers were accepted for quality assessment and data extraction.

Table 3 Number of studies at each stage of sifting and screening

Review stage	Number of studies
Studies captured using search terms in all sources (including duplicates)	1763
Studies captured using search terms in all sources (excluding duplicates)	1192
Studies remaining after title/abstract filter	316
Studies used in review	106

Note: title and abstract filters were largely done simultaneously

Study type and quality appraisal

2.17 Each study was categorised by study type (categorised as type 1-4) and graded for quality using a code '++', '+' or '-', based on the extent to which the potential sources of bias had been minimised. The study types are shown in Table 4 and quality categories in Table 5:

Table 4 Study types

Rating	Definition
1	Meta-analyses, systematic reviews of Randomised Controlled Trials (RCTs) or RCTs.
2	Systematic reviews of, or individual, non-randomised controlled trials, controlled before-and-after (CBA) or comparative studies, correlation studies.
3	Non-analytical studies, for example, case reports, case series studies.
4	Expert opinion, formal consensus.

Table 5 Study quality categories

Rating	Definition
++	All or most of the methodological criteria have been fulfilled. Where they have not been fulfilled the conclusions are thought very unlikely to alter (low risk of bias).
+	Some of the criteria have been fulfilled. Those criteria that have not been fulfilled or not adequately described are thought unlikely to alter the conclusions (risk of bias).
-	Few or no criteria have been fulfilled. The conclusions of the study are thought likely or very likely to alter with further investigation/experimentation (high risk of bias).

2.18 Seventeen type 1 studies were found. Eighty-three studies were categorised as type 2 with the remaining six as type 3. Thirty-two studies were categorised as (-) quality with 61 studies categorised as (+) and 13 as (++). The main reasons for studies being assessed as (-) quality were failure to take potential confounders into account, or difficulty in controlling for confounders, and often low, or no, replication of treatments. Sampling effort may have been low, or measurements made infrequently or over short timescales. Studies assessed as (+) were often well-designed and described, but with low replication and/or the likelihood of some environmental differences between comparison areas.

Study categorisation

Description of studies

2.19 The 106 studies are described in sections presenting the summary of findings. They include:

- 22 Randomised, replicated and controlled trial studies;
- 21 Non-randomised, replicated and controlled trial studies;
- 15 non-replicated, controlled trial studies;
- 13 Comparison studies (often grazed vs non-grazed);
- 24 Correlative (including monitoring) studies;
- 9 Non analytical/observational studies; and
- 2 Analysis of data from a number of studies.

2.20 These studies tested a range of different environmental interventions related to the effects of livestock grazing or lack of it on moorland biodiversity and ecosystem services. They fell into five different categories:

- sheep stocking rates/grazing intensity and period;
- cattle and mixed sheep/cattle grazing and occasionally other grazing species;
- grazing exclusion;
- grazing and burning interactions; and
- grazing and nutrient addition interactions.

2.21 Studies often fell into more than one of the above categories as they tested a range of interventions. Few studies were found that considered the direct effects of spatial manipulation of grazing, for example, through shepherding or hefting.

Geography of studies

2.22 The majority of studies were conducted in the UK. Table 6 presents the number of studies by area. The majority of studies come from Scotland, where there is a history of grazing research on a number of experimental farms and research stations. A significant number come from northern England however, largely from the experimental farm at Redesdale, Northumberland, and the long establishes research station on Moor House National Nature reserve (NNR) in the North Pennines. Similarly a number of studies come from research facilities in Wales. A small number of studies have collected data from a range of sites, often across country borders.

Table 6 The number of studies by area of origin

Area of origin	Number
N England	22
English Midlands	6
England and Scotland	8
England and Wales	5
Wales	9
N Scotland	23
Central and S Scotland	26
N Ireland	1
Eire	1
French Alps	2
Switzerland	1
Spain	1

Length of outcome measures

2.23 Studies vary greatly in the length of time over which a treatment or land use is in place, and the period of time over which outcomes are measured. In 38 controlled grazing studies treatments were in place for 3-6 years, with a further 6 extended for up to 10 years. Outcomes measures have usually been made regularly over these periods, but there are a number of long-standing experimental platforms that have been used to make one-off or short-term measures of a particular outcome (eleven studies), but which reflects the longer-term management, for example, soil carbon and water table measures or invertebrate surveys.

2.24 Many studies are monitoring based, with eleven reporting on the impacts of known changes to grazing over the short-medium term (up to fifteen years). A further nineteen make comparisons over time or across different types of vegetation or management, but the detailed continuity of prevailing management and historical change is not known or presented. Thirteen studies are focussed largely on the effects of grazing removal, with three up to 20 years old at time of reporting, three 20-30 years old and seven over 30 years, including the various studies which utilise the Hard Hill site at Moor House NNR. These exclusion areas have often been reported at different time intervals. Again where comparisons are made with the prevailing grazing management, details of current levels and change over the intervening period are often not available. An additional three studies involve observations of sheep ranging behaviour over one grazing unit.

2.25 There is a degree of overlap between different study types and the above is an approximation, but gives a flavour of the range of approaches used in investigating grazing effects.

Assessing applicability

2.26 Each study was assessed on its external validity: that is, whether or not it was directly applicable to the target population(s) and setting(s) in the scope. This assessment took into account where each study was undertaken and any reason why a study may not be relevant or valid for the review. Studies were included which were conducted in the UK, or other areas with similar biogeography and extensive livestock systems, particularly sub-montane and montane areas of northern Europe and Scandinavia. Studies undertaken on enclosed grasslands, particularly where the sward had been modified by fertilizer application or re-seeding, were not considered relevant.

2.27 Topic and literature reviews constituted a significant proportion of the references initially identified for inclusion. These usually did not provide new quantitative data beyond the source studies included in these reviews. Such papers were not subjected to the full assessment process, but checked for additional references that met the criteria for the current review. Often these papers contained usefully contextual and summary information which has been used in the introductory paragraphs to the sub-questions, and in the concluding sections. There were also a significant number of papers concerned with developing or improving predictive models of grazing systems and impacts, which have been treated similarly unless a paper included some experimental data not reported elsewhere, in which case it was fully evaluated.

Synthesis

2.28 It was not appropriate to use meta-analysis to synthesise the outcome data as interventions, methods and outcomes were heterogeneous. This review is restricted to a narrative overview of all studies that met the inclusion criteria and contained sufficient data for data extraction and quality assessment. The studies were examined within the effects identified by the impact of grazing sub-questions: impacts of stocking rate; timing of grazing; and livestock; or removal of grazing; on: vegetation type, composition and condition; birds, and other vertebrates; invertebrates; soil carbon, nutrient and gas fluxes and hydrology, stratified by study quality. The evidence statements were developed using:

- The best available evidence of the effect of an intervention.
- The strength (quality and quantity) of supporting evidence and its applicability to the populations and settings in question.
- The consistency and direction of the evidence base.

2.29 The strength of evidence is described in terms of strong, moderate, or weak. This is partly a subjective judgment, taking account of not only the number of supporting studies and their quality scores, based on the criteria in Table 5, but also a consideration of the aims and focus of a study. A study may, for example, have a very high quality score based on the design and analysis, and the findings in relation to grazing may be important, but the aims of the study may be wider and cover a range of land management treatments. The strength of evidence is defined as follows:

- **Strong** - evidence from a number of studies, or one or two very high quality studies.
- **Moderate** - evidence from two or three studies, of which at least one must be a minimum of '2+'.
- **Weak** - evidence from one study or a small number of low quality studies, usually includes '– ' scores.

3 Impact of moorland grazing – review of evidence

Standardisation of stocking rates and the livestock unit system

3.1 A significant difficulty in comparing the findings from different grazing studies and applying these to land management systems is the variation in how grazing levels are achieved and described. As well as differences between livestock species and breeds, the duration of grazing, timing and livestock numbers in experimental situations may be quite different from a typical hill grazing situation. Age of animal and breeding status may also be atypical. One way to address this is to express grazing figures as standardised Livestock Units (LU), over a standard area and time. An attempt has been made here to convert key animal numbers to LU ha^{-1} yr^{-1}. The system used is given in Appendix 3. This system takes account of differences between breeds in broad liveweight categories, as well as different species of grazer. Account is also taken of un-weaned young in ascribing livestock units, ie the figures for a ewe include lambs at foot.

3.2 Wherever possible, grazing treatments and regimes described in studies have been standardised using this method. In many cases, often where studies compare only presence and absence of grazing, with the grazing treatment provided by the agricultural regime of the surrounding moorland grazing unit, it is not possible to calculate an average stocking rate.

3.3 However, it should be noted that the conversion to LU is problematic. For instance it hides the seasonality of grazing, does not take into account species and/or breed differences in grazing behaviour and does not equate to levels of off take. It does, however, allow some comparison between different experiments.

The topic review questions

3.4 The overarching question addressed by this topic review is:

What are the effects of grazing regimes and stocking rates on the maintenance and or restoration of moorland biodiversity and ecosystem service delivery?

3.5 To explore the topic more fully, the review question was split into a number of sub-questions or sub-topics, which cover different aspects of moorland grazing and the identification and evaluation of grazing regimes aimed at delivering environmental benefits. Chapters 4 to 11 relate to each of the eight sub-questions and set out the findings from each relevant study, concentration particularly on the findings most pertinent to the sub-question.

3.6 There is inevitably a high degree of inter-relationship between some of the sub-questions and in reviewing evidence papers it was found that many studies cover more than one sub-topic. Where the findings of a study clearly cover more than one sub-topic, the different aspects of the findings are reported separately in the relevant chapters.

3.7 The first sub-question is quite general and reflects the over-arching question. The majority of studies are therefore reported under this section, and possibly under other relevant sub-questions, unless the findings are focused largely on one of the other sub-topics.

3.8 The scope of the review covers the effects of grazing on biodiversity and ecosystem services. For each sub-question the studies are grouped according to the particular outcomes assessed. The range of outcomes for which research is available varies between sub-questions but is generally:

- habitat type or mosaics;
- particular plant species or species groups;
- moorland birds;
- invertebrates;
- soils – stability, carbon storage; and
- hydrology.

The structure of the evidence

3.9 Each chapter starts with a general introduction to the sub-question, followed by a summary of the evidence in statements that draw together related findings from a number of studies, with an evaluation of the strength of evidence, according to the definitions in paragraphs 2.28-2.29. This is followed by précis of the key findings from individual studies, relevant to the sub-question. Individual summaries of the methods for each study and relevant background information are presented in Appendix 4.

3.10 The various evidence conclusions identified under each sub-question are repeated in Chapter 12, grouped into a number of key conclusions which may draw in evidence identified under more than one sub-question. A narrative discussion covering the conclusions and identifying recommendations and evidence gaps is presented in Chapter 13.

4 What is the effect of grazing on moorland biodiversity and other ecosystem services, including timing, frequency and regularity of grazing as well as livestock numbers, and what are the differential effects on integrated moorland ecosystem services?

Introduction

4.1 It is generally perceived that increased grazing, primarily by sheep in English uplands, over the second half of the 20th century has had negative effects on biodiversity, as discussed under Historic context in the introductory chapter. The main mechanisms by which this occurs is through selective grazing of preferred species, typically bent grasses *Agrostis spp*. and sheep's fescue *Festuca* ovina, leading to a dominance of less preferred graminoids such as mat grass *Nardus stricta*, purple moor-grass *Molinia caerulea* and heath rush *Juncus squarrosus* (for example, Crawley, 2004), along with reduced structural diversity. Re-distribution of nutrients through dung and urine deposition affects plant competitive inter-actions, and trampling can have a direct impact on sensitive and slow growing species. Recent reductions in grazing have given rise to concerns of unfavourable conditions for some habitats and species through increased shading and competition on lower growing plants and loss of short, open vegetation. The effects of a given level of grazing will vary with vegetation productivity, which is in turn influenced by soil nutrients, climate and exposure. A similar level of grazing that maintains species diversity on calcareous grassland may result in suppression of dwarf shrub and grass dominance on acidic heathland, and physical damage to a montane moss heath.

4.2 This section includes studies of grazing impacts on different vegetation types. Some focus on the effects of grazing on dwarf shrub heath and the dynamics of change between heath and grass dominated communities, and include landscape-scale studies, with the others paddock or plot-scale. Other upland and montane habitat are covered, including blanket bog and montane heath.

4.3 A number of studies consider the effects of grazing on the balance of preferred to less preferred grasses and the use of grazing to control dominant grasses. Several studies consider the effects of nutrient addition, to address concerns over high levels of atmospheric deposition in upland areas. Studies which investigate interactions with grazing, including through simulated deposition treatments, are covered here.

4.4 Effects of grazing on moorland birds and other vertebrates are considered in a number of studies. Experimental studies often focus on a single species, whilst a correlative approach is often used to attempt to identify key variables that influence moorland bird assemblages. A number of studies consider different invertebrate groups, including some that are key food groups for moorland birds.

4.5 Finally, a small number of studies consider grazing effects on soil or soil processes, including soil stability, carbon storage and microbial processes.

Summary of evidence of the impacts of grazing on biodiversity and ecosystem services

Effects of grazing on the balance of preferred to less preferred grasses and the use of grazing to control dominant grasses

4.6 There is strong evidence Hulme *et al.* (1999) [1+]; Grant *et al.* (1996a) [2+]; Ross (2000) [2+]; Hulme *et al.* (2002) [2++]; Grant *et al.* (1996b [2-]; Critchley *et al.* (2008) [2-] that grazing influences the occurrence of species that are less preferred by livestock and, where these species become dominant, can be detrimental to habitat conservation. There is strong evidence that heavy sheep grazing facilitates the spread of *Nardus* on low fertility soils Hulme *et al.* (1999) [1+]; Grant *et al.* (1996b [2-]. There is moderate evidence that cattle grazing either alone Grant *et al.* (1996a) [2+], or in combination with sheep Critchley *et al.* (2008) [2-] reduced the cover and biomass of *Molinia* compared with sheep-only grazing, under which it increased when stocked at ESA stocking rates, with utilization rates estimated at around 33% Critchley *et al.* (2008) [2-].

4.7 There is moderate evidence that in restoration trials sheep grazing can exert some control on *Molinia* when in combination with other treatments such as burning Ross (2000) [2+] or cutting Milligan *et al.* (2004) [2-]. This study and Marrs *et al.* (2004) [2+] provide moderate evidence for the positive effect of sheep grazing in combination with other treatments in the development of moorland communities, where heathland species are present.

Effects of grazing on dwarf shrub heath and the dynamics of change between heath and grass dominated communities

4.8 There is weak evidence Deléglise *et al.* (2011a) [2+] that grazing maintains fine-scale plant species diversity in moderately productive heath and grass communities.

4.9 There is moderate evidence from correlative studies Cooper *et al.* (1993) [2++]; Anderson & Yalden (1981) [3+] of a negative association between sheep grazing pressure and heather moorland and blanket bog condition at the landscape scale.

4.10 There is moderate evidence for sheep grazing to favour *Calluna* over *Vaccinium myrtillus* (i.e. *Vaccinium* is preferentially grazed favouring the expansion of heather) Welch 1998 [2+], with greatest effect in autumn Welch 1998 [2+]; Gardner *et al.* 2002 [2+]. There is weak evidence that grazing favours *Nardus* over *Vaccinium*, but that *Deschampsia flexuosa* is favoured by no grazing Gardner *et al.* 2002 [2+].

4.11 Pakeman *et al.* (2003) [1+] and Pakeman & Nolan (2009) [1++] provide strong evidence that reducing grazing favours heather over grass, except where there is winter-only grazing of communities of mixed *Calluna* and *Molinia* Hulme *et al.* (2002) [2++]. However there is weak evidence Gardner *et al.* (2002) [2-]; Critchley *et al.* (2008) [2-] that under reduced sheep grazing vegetation community change, including dwarf shrub expansion, may be limited.

4.12 There is moderate evidence that utilisation of dwarf-shrubs by sheep is lower in summer Hulme *et al.* (2002) [2++] and greater in autumn/winter Welch *et al.* (1998) [2+], Gardiner *et al*. (2002) [2+]; Welch (1984 a, b)[2-], and weak evidence Grant *et al.* (1985a) [2+] that there is an interaction between grazing pressure and heather age, with the effect of heavy grazing more marked in older heather.

4.13 There is moderate evidence Mitchell *et al.* (2008) [2++]; Critchley *et al.* (in press) [2++] that where heather is undergoing restoration from seed, summer cattle grazing, in the absence of sheep, can be almost as effective as complete grazing exclusion in facilitating establishment.

4.14 There is moderate evidence that light sheep grazing (0.01-0.05 LU ha^{-1} yr^{-1}) reduces heather cover on blanket bog Rawes & Hobbs (1979)[2+]; Welch & Rawes (1966) [2-] and moderate evidence from the same sources that grazing removal or reduction from even very low levels benefits lichen abundance and biomass. Moderate evidence that high levels of grazing reduce moss cover in alpine heath Welch *et al.* (2005)[2+]; Britton *et al.* (2005) [2-].

Interaction of grazing with nitrogen deposition

4.15 There is moderate evidence Hartley & Mitchell (2005) [2+]; Hartley (1997) [2-]; Van der Wal *et al.* (2003) [2-]; Gordon *et al.* (2001) [2-] of an interaction between nitrogen (N) deposition and local grazing pressure, and interactive effects on vegetation. Van der Wal *et al.* (2003) [2-] showed that N addition significantly increased grass cover at the expense of moss in montane heath communities, which in turn encouraged higher grazing and trampling pressure. Hartley & Mitchell (2005) [2+]; Hartley (1997) [2-] showed that N addition increased heather growth in the absence of grazing, but heather decreased and graminoids increased where grazing was present, due to increased grazing on fertilized plants. Gordon *et al.* (2001) [2-] found that reduced grazing pressure appeared to increase the sensitivity of mosses, lichens and *Vaccinium myrtillus* to N addition.

Effect of grazing on bird populations and dynamics and other vertebrates

4.16 Strong evidence of grazing-related effects on upland bird populations comes from Pearce-Higgins & Grant (2006) [2+]; (2000) [2-] who showed that meadow pipits favoured intermediate (c. 30%) heather cover and skylark densities were highest on short grass moorland, but that red grouse and stonechat would be affected by loss of heather cover; and Jenkins & Watson (2001) [3-] who documented declines in moorland birds on grazing units subject to increased sheep grazing. Amar *et al.* (2011) [2+] found a relationship between hen harrier recovery in Orkney, with changes in sheep numbers. There is moderate evidence for an increase in vole numbers with grazing reduction or removal Evans *et al.* (2006b) [1+]; Amar *et al.* (2011) [2+].

4.17 There is strong evidence that grazing abandonment reduces meadow pipit populations, compared to low intensity sheep and mixed grazing, up to 0.1 LU ha^{-1} yr^{-1}, probably through reduced prey availability and effects on territory size Evans *et al.* (2005) [1+], Evans *et al.* (2006a) [1+], Vandenberghe *et al.* (2009) [1+].

4.18 Baines (1996)[2+], and Calladine *et al.* (2002)[2+] provide moderate evidence that positive trends in black grouse numbers are most likely where moorland is lightly grazed. There is weaker evidence however that vegetation can become too uniform and dense under prolonged low grazing levels.

Effects of grazing on invertebrates

4.19 There is strong evidence Dennis *et al.* (2001) [2++]; Dennis *et al*. (2008) [1+]; Littlewood (2008) [1++]; Littlewood *et al.* (2012) [1++] that grazing removal increases invertebrate abundance. There is also strong evidence that grazing intensity and seasonality affects species assemblages and functional groups represented Dennis *et al.* (1997) [2++]; Dennis *et al.* (2001) [2++]; Dennis *et al.* (2002) [2++]; Dennis *et al.* (2008) [1+]; Littlewood (2008) [1++]; Cole *et al.* (2010) [2+]; Littlewood *et al.* (2012) [1++].

4.20 There is moderate evidence that mixed low intensity regimes of sheep and cattle can benefit some invertebrate groups and can have a positive effect on invertebrate biomass Dennis *et al.* (1997) [2++]; Dennis *et al.* (2008) [1+]. Taller vegetation buffers against environmental extremes, and low disturbance favours larger bodied inverts with longer life-cycles. However, there is strong evidence Vandenberghe *et al.* (2009) [1+]; Douglas *et al.* (2008) [2-] that uniformly tall swards and particularly ungrazed swards Evans *et al.* (2005) [1+], Evans *et al.* (2006a) [1+], Vandenberghe *et al.* (2009) [1+] may limit the availability of invertebrate prey to birds such as meadow pipit.

4.21 There is moderate evidence Dennis *et al.* (2001) [2++]; Dennis *et al*. (2002)[2++] that some species and groups including spiders, harvestmen and pseudoscorpions fared better under light sheep grazing than mixed sheep and cattle grazing, and that some species of beetle, particularly smaller-bodied species, are associated with more heavily grazed grassland Dennis *et al.* (1997) [2++]; Cole *et al.* (2010) [2+].

4.22 There is moderate evidence Littlewood *et al.* (2006c) [2++] that the diversity of the Hemipteran assemblage is strongly influenced by plant species composition, and may increase with conversion of heathland to grassland through heavy grazing. However, changes in the assemblage include a loss of heathland species.

Grazing and soils

4.23 There is moderate evidence from Evans (1977) [2+]; Anderson & Radford (1994) [2-] and Evans (2005) [3+] of a link between sheep grazing and soil erosion through the creation of bare ground. These studies also provide moderate evidence that plant recolonisation can take place with grazing reduction. There is moderate evidence from grass and heath habitats that grazing affects soil microbial communities, with reduced microbial biomass in ungrazed situations Bardgett *et al.* (2001) [2+]; Medina-Roldán *et al.* (2012) [2+]. There is weak evidence Bardgett *et al.* (2001) [2+] that microbial biomass and associated nutrient cycling processes are greatest at low to intermediate grazing levels, although Ward *et al.* (2007) [1+] did not detect a difference in soil microbial processes between grazed and ungrazed plots. There is weak evidence Bardgett *et al.* (2001) [2+] that bacteria dominate soil communities under heavy grazing with a proportionately greater contribution from fungi under light or no-grazing.

4.24 There is moderate evidence Ward *et al.* (2007) [1+]; Medina-Roldán *et al.* (2012) [2+] that grazing removal increases above ground C storage in vegetation and litter layer, especially where it results in an increase in dwarf shrub. There is also moderate evidence Garnett *et al.* (2000) [1+]; Ward *et al.* (2007) [1+]; Medina-Roldán *et al.* (2012) [2+] that the rate of carbon accumulation in moorland soils is not significantly affected by grazing removal, over periods of up to 30 years, but Bardgett *et al.* (2001) [2+] provide weak evidence of trends towards greater soil C storage along landscape-scale transitions to lightly or infrequently grazed and disturbed habitats. There is weak evidence of increased CO_2 sinks in grazed peatland plots Ward *et al.* (2007) [1+] but higher CH_4 effluxes.

4.25 The is weak evidence that water tables are affected by grazing (closer to the soil surface), and that it could improve rates of peat formation if the abundance of peat forming species is not affected Worrall *et al.* (2007) [1-]; Clay *et al.* (2009) [1-]. There is weak evidence Worrall *et al.* (2007) [1-]; Worrall *et al.* (2008) [1-] that at low stocking rates grazing has little impact on soil water quality in peatlands.

Analysis and evidence statements

Effect of grazing on different vegetation types

4.26 Deléglise *et al.* (2011a) [2+] found that species richness was affected by grazing at grain sizes (scales) of 25 cm x 25 cm and above, but the effect differed between communities. In heath and mesic grassland evenness and species-richness was higher in the grazed plots, and in xeric calcareous grassland in the ungrazed plots. For the former two communities evenness was lower in ungrazed plots at scales up to 15 cm x 15 cm, with no difference in xeric grassland. This suggests that grazing probably influences species-richness at the community scale through changes in distribution of relative dominance at the very fine scale. The variability of species composition showed significant differences between grazed and ungrazed plots at all grain sized other than the smallest (5 cm x 5 cm) as dissimilarities in species composition was greater with grazing exclusion compared to grazing in all the three communities. This reflects the finer scale of heterogeneity maintained through grazing.

4.27 The findings support the generally held view that in more productive environments moderate grazing pressure can increase plant diversity through reducing competition and increasing heterogeneity of resource availability and establishment opportunities. In low productivity environments other environmental stress limits competition whilst defoliation and trampling can have adverse impacts.

Effect of grazing on the balance of preferred to less preferred species and grazing control of dominant grasses

4.28 Hulme *et al.* (1999) [1+] demonstrated that sheep grazing days required to achieve the sward height treatments (3 cm, 4.5 cm, 6 cm) on the more productive community over brown earth were typically 2-3 times that required at the podzolic site. There was little overall change in composition over 7 years. The heavy grazing (low sward height) treatment at the low productivity site allowed *Nardus* to spread and at the productive site where *Nardus* was absent resulted in an increase in moss. Least change was associated with 4.5 cm treatment at the productive and 6 cm at the moorland site.

4.29 Ross, 2000 [2-] found that summer-only grazing by sheep was effective in controlling *Molinia* in the three years following burning. A grazing level set to remove approximately 33% of the annual leaf growth was effective at reducing cover whilst allowing heather seedling regeneration. The higher utilization rate of 66% compromised heather regeneration.

4.30 Marrs *et al.* (2004) [2+] found that grazing had negligible significant effects on sward height of recovering *Molinia* over the 6 years, but the tallest vegetation was found in the grazing exclusion plots (however stocking densities were low and only sheep were used in the experiment). A greater positive effect of grazing was shown on moorland-bog development of grey (*Molinia-Calluna*) sites than on white (*Molinia*) sites.

4.31 Milligan *et al.* (2004) [2-] found that the most successful treatment for controlling *Molinia* was three cuts per year plus grazing. The effect of cutting 3 times reduced vegetation height, and this effect was still observed 44 months after treatment. Grazing (ESA rates) alone had lesser effect on *Molinia*, but including grazing generally produced vegetation that had the greatest moorland species complement. Lack of grazing tended towards species-poor acid grassland.

4.32 Grant *et al.* (1996a) [2+] demonstrated that three years of summer biomass removal (clipping) reduced leaf production in the following season by 40% where 33% of annual growth had been removed, and 78% where 66% of annual growth removed. Six years of grazing by cattle to remove similar proportions of herbage showed subsequent reductions in *Molinia* biomass by 46-65% and 86% compared to ungrazed, under the low and high defoliation rates respectively. Floristic diversity consistently increased in grazed plots, primarily through increased cover of other broad-leafed grasses.

4.33 Grant *et al.* (1996b) [2-] found that *Nardus* biomass was greater on both sheep plots than the cattle plot at the end of the experiment, and had increased in both sheep treatments. Cattle were observed to uproot more *Nardus* than sheep. Grazing on *Nardus* tillers was highest in the cattle plot, and lowest in the light sheep grazed plot, with utilisation falling over time on the sheep grazed plots. Growth was greatest in the light sheep grazed plot than the other two, and there was a significant increase in the growth rate over time. Although there were differences between years reflecting growing conditions, tiller base weights and total water soluble carbon (TWSC) were consistently lower in cattle grazed plots.

4.34 Whilst *Nardus* cover was initially similar at 55%, it had declined to 30% on cattle plots and increased to 86% and 72% on the sheep 4.5 cm and 3.5 cm treatments respectively. Broad-leaved grasses increased in the cattle and light sheep plot. *Deschampsia flexuosa* declined on the heavy sheep-grazed plot.

Dwarf shrub heath and related communities

4.35 Anderson & Yalden (1981) [3+] through re-mapping of Peak District moorland measured a net loss of 56 km^2 of heather from 1913 to 1979, leaving 64% of its former extent. Heath had generally been replaced by grassland dominated by *Deschampsia flexuosa* and *Nardus* with *Vaccinium myrtillus*. Sheep numbers overall increased almost four-fold between the 1930s and 1970s. The pattern held at the parish level. The average stocking rate in 1977 was 2.07 sheep ha^{-1} (0.21 LU ha^{-1} yr^{-1}) compared to 0.7 sheep ha^{-1} (0.07 LU ha^{-1} yr^{-1}) in the 1930s. Estimates of loss of grouse are put between 85,000 and 118,000, depending on approach taken (grouse bags, habitat loss).

4.36 Cooper *et al.* (1997) [2++] used land cover and vegetation data to assess variation in upland heath and bog communities in Northern Ireland. Grazing was shown to be the main management factor associated with variation in species composition of between different upland areas, along with peat wetness and slope. Light grazing was associated with dwarf shrub, hare's-tail cotton grass and some Sphagnum species, where heavier grazing was associated with mat grass but also carnation sedge, round-leaved sundew and *Sphagnum auriculatum*. Blanket bog communities M17 (*Trichophorum cespitosum-Eriophorum vaginatum*) and M19 (*Calluna vulgaris-Eriophorum vaginatum*) were associated with lightly grazed, deeper peats.

4.37 Grant (1968) [2-] showed there was a tendency for time taken to reach 50% cover to be longer for older heather after burning. Regeneration of young heather was always quicker as more takes place from shoot bases than in older heather. Sheep grazing on burned areas tended to be higher in early years when heather was short, reducing over time. This effect varied, depending on factors such as wetness, proximity of better grazing on grass, or surrounding tall heather restricting movement. Grazing by hare and grouse had a significant effect at some sites- reducing the difference between the open and enclosed areas. Trampling emphasised cotton-grass humockiness compared with exclosures, and treading caused the break-up of un-colonised peat surface. Treading can however also help to consolidate soil surfaces, with seedlings shown to be thickest along sheep-trods at some sites.

4.38 Welch (1984 a, b) [2-] carried out a large-scale correlative study of the effects of grazing of livestock and wild herbivores on heather moorland at thirty two sites. Annual average stocking rates across all sites were calculated as 0.3 cattle ha^{-1}; 0.4 red deer ha^{-1}; 1.0 sheep ha^{-1}. However, the highest estimates for cattle and sheep were four times greater than the average. The factors which most influenced occupance were nearness to improved grasslands or swards containing preferred graminoids, and the role of each moorland tract in the management of the farm to which it belonged. The attractiveness of *Calluna* to grazing animals increased in winter compared to graminoids. Heather declined under heavier grazing and increased mainly at sites receiving little dung. Cover was found to increase less than height under light grazing, and decreased more rapidly than mean height under heavy grazing. Herbivores usually selected for the current year's growth and the biggest losses in cover, height and biomass were all less than the biggest gains. Ruminants consumed some older growth and broke branches by feeding and trampling. Cattle were found to affect heather more severely than other animals, based on dung deposition measurements. From regressions, the threshold above which heather would decline was calculated at around 0.21 LU ha^{-1} yr^{-1} for cattle and 0.27 LU ha^{-1} yr^{-1} for sheep. The large depositions of cattle dung often killed heather, giving niches quickly colonized by herbs and graminoids, whilst viable seeds of these plants were transmitted in the dung.

4.39 Welch (1985) [2-] showed that seedlings that arose by germination from dung gained much less cover than plants colonising the deposits vegetatively. However, several species transmitted in cattle dung attained greater cover than in the previously existing vegetation, for example, *Cerastium holosteoides, Lolium perenne, Poa annua, Poa pratensis, Rumex acetosella, Stellaria* media and *Veronica serpyllifolia*. Surveys showed that *Anthoxanthum* *odoratum*, *Holcus lanatus, Poa annua* and *Poa pratensis* were the grasses most frequently introduced to moorland sites and increases in the number of their establishments was associated with heavy dung deposition by cattle. The contribution of dunging to the overall impact of the herbivores on the composition of the vegetation was appreciable only with cattle, but the gains in cover of graminoids and herbs were less than the decline in *Calluna vulgaris* due to plant mortality below the deposits. Dunging was thought to have caused about a quarter of the greater cattle (compared to sheep) impact on heather.

4.40 Welch *et al.* (1998) [2+] found that in winter-grazed plots sheep showed a preference for *Calluna-Vaccinium myrtillus* than pure *V.myrtillus* plots. Although seasonal effects varied between sites, sheep consistently chose to graze the *V.myrtillus* sward more heavily in autumn than the rest of the year. Occupancy on winter-grazed plots remained high into the October-December period as almost all of the previously protected summer growth was available to graze. The greatest increase in *V.myrtillus* utilisation was recorded in August-October, and October-January for heather. In the ungrazed plots, both *V.myrtillus* and *Calluna* grew significantly taller, and the grass component and *Empetrum nigrum* increased significantly, whilst *Nardus* decreased. At the heather-*V.myrtillus* site, heather increased in cover and height at the expense of *V.myrtillus* cover under all grazing treatments, despite an average grazing pressure of 1.4 sheep ha^{-1} yr^{-1} (0.11 LU ha^{-1} yr^{-1}), based on conversion rate of 17 pellet groups $sheep^{-1}$ day^{-1}.

4.41 Hulme *et al.* (2002) [2++] found that utilisation in all grazed treatments was within the range in which heather is thought to be able to maintain its growth, and resulted in similar responses in height and frequency increase between treatments. Reduction in utilisation was not proportional to sheep number reductions, and was greatest in summer-only grazing when palatable grass growth is at a maximum. Lack of summer grazing allowed *Molinia* to thrive, even though heather utilisation was low enough not to affect growth of this species. Summer grazing kept *Molinia* in check, whilst exclosure (ungrazed) increased the competition from heather.

4.42 Pakeman *et al.* (2003) [1+] found that on the dry heath system studied, a reduction in sheep numbers to 0.8-0.9 sheep ha^{-1} yr^{-1} (0.08-0.09 LU ha^{-1} yr^{-1}) to give utilisation levels below 20% was seen to achieve the desired result of improving vegetation condition for the proportions of heather and grass at the study site. There was little effect of timing of grazing. There was some heather recovery under all treatments (low and high rates applied in each of winter and summer), which were reductions on the control. Rabbits were shown to have a measurable negative effect on heather recovery.

4.43 Pakeman & Nolan (2009) [1++] found, from analysis of the ten experiments, there was a clear relationship between rate of change in the proportion of heather and its utilisation. Factors of season, region and growth phase were not found to be significant. The relationship between stocking rate and percentage utilisation was strong, with an increase of 15.1% for each 1 sheep ha^{-1} yr^{-1}. However, as most of the sites were established on a mix of heather and grass, the no-effect stocking rate is meaningless as it varies with the proportion of preferred grass species in the vegetation.

4.44 Critchley *et al.* (2008) [2-] showed that in mixed grazing paddocks (sheep with summer cattle), *Molinia* cover declined substantially where it had previously been abundant. *Calluna* also declined slightly, primarily because of localised trampling. *Molinia* cover increased in the sheep-only paddocks and *Calluna* cover declined slightly despite low grazing indices, although there was a significant increase in frequency in the low sheep treatment. Other changes in plant community composition were minor. It was suggested that cows can be grazed in with sheep to remove *Molinia* biomass without detriment to livestock performance, although the stocking levels used in this study would not be sustainable every year. There was no evidence of a significant move towards wet heath communities after 4 years.

4.45 Rushton *et al.* (1996) [2-] detected more dynamic vegetation change at the plot than the field scale, with a marked change in the proportion of quadrats in each vegetation type at this scale. The model predicts increases in the dwarf shrub communities over 10 years, although there is a poor fit between observed and predicted after 5 years. At the field scale there was a predicted (from modelling) and observed increase in heather/bilberry community after 5 years in the lower grazing treatment (0.83 ewes per ha, Apr- Oct). Change appeared to be slow at the Redesdale farm-scale plots, and most communities were expected to persist under the lower stocking rate (0.15 LU ha^{-1}). This reflects the greater buffering capacity of larger areas, the greater heterogeneity of vegetation and the grazing pattern. The accuracy of model predictions increased with the size of the experimental unit, being greatest at the farm scale, where change was slowest. Simplistic management prescriptions may not take adequate account of the ecological processes affecting vegetation at different scales.

4.46 Gardner *et al.* (2002) [2+] reported a range of experiments to investigate the effect of stocking rate, seasonal grazing and spatial grazing patterns on the recovery of dwarf heath communities.

4.47 Effect of ESA stocking rates - There was little change in top cover of species in *Calluna-Nardus* at the ESA tier 1 stocking rate, although there was a decrease in top cover of *Calluna* in this vegetation under tier 2 rates, related to increased cover of other species. On the whole vegetation remained stable across the plots. Greater annual variation in grass and sedge species was observed within the dwarf shrub vegetation under the Tier 2 stocking rates than under the tier 1 stocking rate. *Juncus squarrosus* increased in *Agrostis-Festuca* and *Vaccinium-Nardus* under tier 1 grazing, probably due to reduced grazing in winter and spring.

4.48 Effects of seasonal grazing - Under most grazing treatments *Vaccinium myrtillus* decreased in cover, with corresponding increases in *Nardus* under grazed conditions and *D. flexuosa* under ungrazed conditions. On the longer established paddocks *V. myrtillus* declined under three of the four grazing treatments. Welch (1998) observed reductions in the cover of *V. myrtillus* under grazed and ungrazed conditions on *Calluna-Vaccinium* moorland. The results from this study, albeit from a different vegetation type, tend to support the idea that *V. myrtillus* is sensitive to even relatively low levels of grazing. Cover was only maintained when grazing was concentrated in the three months in spring, which may be because grasses are grazed at this time in preference to *V. myrtillus*, which tends to be grazed in autumn.

4.49 Results contrast with early predictions of Rushton *et al.* (2002) who postulated that the *Nardus- V. myrtillus* plots would move towards heather moorland. There has however been little change in heather cover over the 10 year period. Seed bank studies suggest little *Calluna* seed under *Nardus- V. myrtillus* and grass dominated communities. *V. myrtillus* moorland may be a more viable objective.

4.50 Spatial grazing - Higher levels of grazing on *Calluna* were recorded at the interface between *Calluna* and *Nardus* communities and within the *Calluna* dominated vegetation type than in *Nardus*, and were higher at the end of winter than summer. *V. myrtillus* and *Nardus* grazing were significantly higher in the interface and *Nardus*-dominated vegetation. Within *Nardus*-dominated vegetation, grazing on *V. myrtillus* was greater during the end of summer assessment period than at the end of winter, whereas for the interface community, grazing was greatest at the end of winter.

4.51 The study has highlighted the importance of spatial distribution, plant productivity and species composition in determining the direction and magnitude of vegetation change on upland dwarf shrub heath. There is evidence that the previous heavy grazing may have reduced productivity and hence competitive ability of *V. myrtillus*, resulting in a lag effect when grazing is reduced.

4.52 Mitchell *et al.* (2008) [2++] found the addition of *Calluna* seed to be a key factor in the establishment of *Calluna* on grass-dominated moorlands, with the amount of bare ground, rather than the methods of creation (mechanical vs. trampling) also critical. When the disturbance intensity was low and little bare ground was created, grazing increased *Calluna* occurrence. At the *Nardus* site, grazing by cattle-only had equal or better *Calluna* establishment and growth than no grazing. Grazing by sheep alone was the least successful treatment for the *Nardus* sward. At the *Molinia* site, *Calluna* presence and the number of *Calluna* plants was greater in the grazed than the ungrazed plots; probably due to increased bare ground in grazed plots. However, *Calluna* plants in the grazed plots were much smaller, and further growth under a grazing regime was likely to have been slow. This study showed that low intensity grazing can be a key management tool for the establishment of *Calluna* on grass dominated swards, along with the creation of suitable sites for germination, and the addition of *Calluna* seed. Results suggest that, as well as creating bare ground, disturbance may also limit re-growth of competitive grass species.

4.53 After a further four years Critchley *et al.* (in press) [2++] found that grazing exclusion and cattle grazing had a significant effect on heather morphology, with significantly greater height, number of shoots and dry weight than in either the sheep-only or mixed grazing plots. Heather cover was highest in seeded and rotovated or trampled plots protected from grazing (25-30% cover), and next highest in the same combination of treatments where cattle-only grazed (20-25%). Plots grazed by sheep only had the lowest heather cover, with seed addition having much less effect in these plots. Change in heather cover over the previous four years was significant in ungrazed and cattle-only plots. In disturbed and seeded plots the similarity to target vegetation was highest in ungrazed and cattle-only grazed plots. Overall it would appear that grazing exclusion for an extended period is the best option for heathland restoration, but summer cattle grazing provides a viable alternative.

Blanket bog

4.54 Welch & Rawes (1966) [2-] observed that grazing pressure in three moorland bog areas was inversely related to the amount of heather in the vegetation. The bog with the least heather cover (10.5±4.0%) was grazed by an average of 1 sheep per 4 acres (0.05 LU ha^{-1} yr^{-1}). The bog with tallest heather and highest cover (59.5±5.6%) was grazed in summer only, at less than 1 sheep per 100 acres (0.001 LU ha^{-1} yr^{-1}). The most heavily grazed area had the highest proportion of heath rush and sheep's fescue, though only a few percent each, and also of *Polytrichum* spp. Lichen abundance was greatest in the most lightly grazed plot with highest heather cover. Other blanket bog species showed weak or no trend across the grazing pressures. Where bogs were grazed through winter, grazing peaked in the study areas in February – March, although there were fewer sheep on the fell overall at this time.

4.55 Rawes & Hobbs (1979) [2+] found that following exclusion of sheep there was a marked change to the vegetation of *Eriophorum vaginatum* dominated blanket bog in the North Pennines. There were increases in *Calluna* at both the 7 year and 18 year timeframes and a corresponding decline in *E. vaginatum*. The increase of *Calluna* at 18 years was not significant but the continued decline of *E. vaginatum* was. Lichen response was also marked with increases in both cover and biomass. The mapping work focussed on the wettest blanket bog. This also showed increases in *Calluna,* but it is acknowledged that climatic factors could account for this and there was poor control. An increase in sheep grazing from 0.01 LU ha^{-1} yr^{-1} to 0.04 LU ha^{-1} yr^{-1} had no measurable impact on botanical composition of blanket bog. Greatly increasing grazing pressure to 0.34 LU ha^{-1} yr^{-1} had a marked impact. *Calluna* was lost and *E. vaginatum* increased, but following cessation of heavy grazing the community did not return quickly to its former composition. It was concluded that it is clear that sheep grazing has a major influence in determining the botanical composition of blanket bogs.

4.56 Grant *et al.* (1985a) [2+] showed that on blanket bog vegetation (approximating to M17 *Scirpus cespitosus-Eriophorum vaginatum* mire) biomass increased over the ten-year survey period as heather aged, and differences between older and recently burned heather diminished. Over time biomass and green shoot production was reduced on heavily grazed (equivalent to 0.22 LU ha^{-1} yr^{-1} annual average) plots compared with light (0.04 LU ha^{-1} yr^{-1}, including off-wintering) and intermediate grazing. The effect of heavy grazing on heather cover was much more marked in older heather. Cover of *E. vaginatum* was reduced at high stocking rates on year-round systems. The area of bare ground was higher on heavy grazed treatments, and significantly increased over time on the older heather plot. Decrease in sward density was similarly highest in the heavily grazed older heather plot. Overall the sensitivity of vegetation to grazing was greatly influenced by initial composition and age since burning. Sensitivity to grazing appeared to increase after eight years, which may be related to climate and increasing heather age.

Other upland and montane habitats

4.57 Welch *et al.* (2005) [2+] found that altering the grazing patterns of free-ranging sheep through, in this case, the provision of shelter, has resulted in a significant reduction in key moss heath species and increased cover of grass in the 15 m zone adjacent to the fence. Pellet group (dung) density was 4-5 times higher in this zone than distant from the fence. There is indication though of on-going slow loss of lichens and bilberry, suggesting grazing-related modification, at the background grazing levels recorded >20 m from the fence, although conditions appeared to remain favourable for nesting dotterel here. A sharp fall in the cover of *Racomitrium* moss was however associated with an increase in sheep occupancy of 25%, from pellet group counts, compared to the background levels (45 pellet groups 100 m-2 yr^{-1} compared to 31 groups 100m-2 yr^{-1}). It would appear that the balance of *Racomitrium* and grass changed rapidly before monitoring commenced (6 years from erection of fence). See also Van der Wal *et al.* (2003).

4.58 Britton *et al.* (2005) [2-] from soil and tissue chemistry suggested that Snowdonia montane heath sites are exposed to high N deposition from the atmosphere, and/or dung and urine. Sheep appear to favour *Vaccinium myrtillus* plots in early summer. It is likely that habitat degradation occurred rapidly in early years of increased grazing (see Welch, 2005 – loss of *Racomitrium* in response to increased grazing pressure). Degradation is likely to be on-going at this site however, as dung counts suggested high grazing pressure. Overall results show that the organic horizon has been lost under the most severely degraded vegetation, so physical and chemical conditions are likely to be unfavourable for re-colonisation and species restoration likely to be very slow. Restoration would perhaps best be targeted where characteristic species are still present.

Interaction of grazing and nutrient addition

4.59 Hartley (1997) [2-] On unfenced sites fertiliser addition (75 kg ha^{-1} yr^{-1} N, 12.5 P and 25 K) was associated with decreased heather cover, but it increased on fenced sites. *Nardus* showed a marked increase in height on unfenced plots compared to those fenced. The apparent benefit to *Nardus* in unfenced areas is an indirect effect of sheep being attracted to fertilised patches and grazing heather. In the absence of grazing, nitrogen (N) addition increased heather cover, at the expense of *Nardus* through shading effects. High N additions above the critical load do not necessarily lead to heather loss, in the absence of grazing.

4.60 Hartley & Mitchell (2005) [2+] followed the above experiment for a further three years and showed heather cover continued to increase in fenced plots at all sites by up to 20%, whereas on grazed plots heather decreased by 20-30% on all sites. Fencing had led to a significantly reduced grass cover whilst on grazed plots grasses showed an average of 20-30% increase in cover at all sites after 6 years. The effects reported in Hartley (1997) continued, Nitrogen addition decreased heather cover and increased grass cover on grazed plots, but not on plots protected from grazing. More heather shoots were browsed on N treated plots than unfertilized ones. Plots were diverging after 6 years such that ericoids were more abundant in ungrazed plots, and bilberry in ungrazed and unfertilized plots. Graminoids, including heath rush and deer grass, were more common in grazed plots. Thus the impact of N on the cover of heather and competing grasses critically depends on the level of grazing.

4.61 Gordon *et al.* (2001) [2-] found at these N saturated sites that N cycling and loss through leaching was higher in grazed than non-grazed areas at elevated N addition, but there was no relationship with relative grazing pressure. Site wetness and compaction may promote anaerobic loss of N. There were differences in the relative contribution of species in the grazing treatments at the start of the study, with a greater biomass of mat grass and moss species and decreased contribution of *Vaccinium myrtillus* in the heavy grazing treatment. The cover of mosses and lichens generally declined with N addition. The sensitivity of these and *V. myrtillus* to N deposition appeared to be highest at the lower grazing pressure possibly due to increased structure for capture, increased competition for light, or lower phosphate limitation. Light grazing may have allowed a greater proportion of N sensitive species to survive in the sward prior to N addition treatments. There was some (non-significant) evidence of preferential grazing by sheep on N addition plots. The increased sensitivity of some species at lower grazing pressures may offset benefits of reduced grazing in areas of high N deposition.

4.62 Van der Wal *et al.* (2003) [2-] demonstrated that N application resulted in significant loss of *Racomitrium* and increase in graminoid cover, with effects most marked at the high N (40 kg ha^{-1} yr^{-1}) treatments. Increased grass cover also attracts sheep, with associated increases in trampling. Exclusion cages showed that *Racomitrium* growth was 40% lower in grazed plots. Along a gradient of increasing sheep grazing density (as reported in Welch *et al.* 2005) a marked decline in *Racomitrium* and corresponding increase in grass dominance was observed, to almost no *Racomitrium* at densities estimated at 4 sheep per ha, from summer dung counts. Nitrogen toxicity to moss, fertilization of graminoids, shading of moss and attraction of herbivores together lead to the replacement of moss-dominated vegetation by grasses and sedges in montane moss-heath.

Effects on moorland birds and other vertebrates

4.63 Jenkins & Watson (2001) [3-] found in the original survey (1957-61) that all parts of the moorland on the estate held golden plover each spring at high density. By 1997 golden plover were not recorded. Where grass has replaced heather since 1961 lapwing, curlew and oystercatcher increased two to four-fold. Numbers of these species were similar in 1997 on heather dominated areas than in the original study period. On a parcel observed to be heavily grazed in the later survey years eighteen red grouse, ten black grouse and six grey partridge had been recorded in 1957 and numbers had remained similar through the 1960s. No individuals of any of these species were recorded in the most recent surveys. The change in areas of vegetation is attributed to increased sheep numbers and grassland expansion.

4.64 Pearce-Higgins & Grant (2002) [2-] showed that skylark densities were highest on short grass moorland, and were negatively associated with bracken and high cover of *Molinia*. Meadow pipit abundance peaked at intermediate heather cover at plot and transect scales. The favoured conditions for both species were thought likely to be grazing influenced. Pipits appear to favour tussocky vegetation, in a fairly uniform sward, at the sample point scale. At the transect scale maximum densities are associated with 30% heather cover. Since pipits are a favoured prey of hen harrier, the suggestion is made that managing for meadow pipits can also benefit this species.

4.65 Pearce-Higgins & Grant (2006) [2+] found from statistical modelling and correlation of a number of vegetation and management variables that loss of heather is likely to reduce habitat availability for red grouse and stonechat, of the nine species studied. Change in vegetation structure and overall heterogeneity may have greater direct effects on several of the species studied than changes from heather to graminoid dominance. Species which require areas of short, open vegetation or structural heterogeneity, notably the waders, may be adversely affected by further declines in livestock numbers.

4.66 Amar *et al.* (2011) [2+] showed that between 1975 and 2008 numbers of fledged hen harriers in mainland Orkney had a negative association with sheep numbers. A decline in sheep numbers since the late 1990's was associated with hen harrier recovery. An increase in the number of rough grassland quadrats between 1999 and 2008 corresponded with an increase in vole (a major prey item) signs but no difference in lagomorphs signs or meadow pipits. No relationship was found between total young fledged and spring or summer temperature, or summer rainfall. A significant negative association was found spring rainfall. A highly significant relationship with sheep abundance was found. These 2 variables accounted for nearly 40% of variation between years.

4.67 Baines (1996) [2-] stated that heavily grazed moors supported 41% fewer invertebrates, with some key groups (*Lepidoptera, Araneae, Hemiptera*) less well represented. Black grouse breeding varied between year and areas but overall was 37% lower on heavily grazed moors, due to reduced availability of invertebrates and greater foraging distances. The higher success on lightly grazed moors was independent of the presence of a gamekeeper. Estimates of 1.5 -2 chicks per year necessary to maintain a stable population were attained on the lightly grazed moors, but not on the heavily grazed moors.

4.68 Calladine *et al.* (2002) [2+] found that displaying male black grouse at leks showed a significantly different trend with an average increase of 4.6% at treatment (reduced grazing) sites, and reduction of 1.7% at reference sites. A similar trend in female birds was non-significant, but was stronger where the treatment area (taken as where low grazing results in a mean sward height of 30 cm or more) is less than 100 ha. A higher percentage of females (54%) at treatment sites had broods than at reference sites (32%). There was no significant difference in brood size, although it was consistently greater at treatment sites. There was weak evidence that numbers of males peaked 5-7 years after grazing was reduced.

4.69 Evans *et al.* (2005) [1+] found, from 82 meadow pipit nests measured, that after less than 1 year, intensively grazed plots (1) contained nests with the smallest eggs and extensively grazed plots [(3) grazed at 2 ewes only at time of study] contained nests with the largest eggs. Ungrazed plots contained eggs with smaller eggs than lightly grazed plots. There was no significant effect of breeding density, laying date or clutch size on egg volume. No effect of egg size or grazing treatment on fledging success was found, which may be due to compensatory mechanisms or effects becoming apparent post-fledging. The mechanisms of effect of grazing and egg size remain unclear. Whilst it is likely that food availability is important, grazing may also affect territory size and hence parental quality, and nest microclimate.

4.70 Evans *et al.* (2006a) [1+] showed that there was a significant effect of cattle grazing days on the number of meadow pipit breeding territories. More territories were found in the mixed grazing treatment (3). The number of territories in low intensity sheep (2) remained fairly constant. Although there was an apparent decline in territories in the intensive sheep treatment (1), no significant effect of sheep density was found. An update from Pakeman (pers comm) however shows the picture changing markedly with the number of breeding territories in plot 3 declining back down to similar levels to the other plots by the 8th year of cattle grazing. The number of territories in treatment (1) increased to the highest densities in 2007 and 2008 before falling markedly. This treatment appears to have greatest variability between years. Treatment (2) has been most stable, and can be considered as a control, being a continuation of the pre-existing grazing. The ungrazed treatment (4) is almost always the worst. The number of territories has declined on all treatments since 2007.

4.71 Douglas *et al.* (2008) [2-] concludes that foraging sites had lower vegetation height and higher total arthropod biomass than control sites and that therefore, in heavily grazed upland systems, meadow pipits select foraging sites that optimise total food abundance and accessibility. However, the difference in the cumulative biomass of selected prey types between foraging sites and control sites was not statistically significant.

4.72 Vandenberghe *et al.* (2009) [1+] observed that meadow pipits tended to forage in areas with lower vegetation height and density and with a lower proportion of the dominant tussock-forming grass *Molinia* caerulea. They did not forage in areas with a total higher invertebrate biomass but the foraging sites in the preferred vegetation type tended to have higher invertebrate biomass than similar vegetation at random sites. Foraging distance was greater in the more heavily grazed plots. Food accessibility seems to become an even more important criterion under high grazing intensity, where prey abundance and size decrease. In this study a low intensity mixed grazing regime seemed to provide a more suitable combination of sward height and structural diversity and food supply for foraging meadow pipits than more intensive sheep-dominated grazing.

4.73 Evans *et al.* (2006b) [1+] after 2 years, a significantly higher abundance of voles was found in the extensively grazed mixed treatment [(3) cattle and sheep] than in the extensively grazed treatment that contained only sheep (2), and particularly the intensively grazed treatment (1). Densities were highest in the ungrazed treatment. The results suggest that low intensity and mixed livestock grazing could help manage vole populations in establishing woodland, whilst also improving availability to raptors through increased heterogeneity of vegetation.

Effects of grazing on invertebrates

4.74 Dennis *et al.* (1997) [2++] identified 32 species of carabid (ground) and staphylinid (rove) beetles that were captured in high enough numbers to include in the analysis. Eight species did not respond to the differences in grazing treatment. Ten species were correlated with heavier grazing intensity, six species with taller mean vegetation height, and eight species with the light grazing or ungrazed treatments. It was suggested that a rotation of varied management over time, different combinations of grazers and varied grazing intensities would encourage a wider diversity of *Coleoptera* by creating a mosaic of structurally varied grassland patches.

4.75 Dennis *et al.* (2001) [2++] demonstrated a significant effect of grazing treatment on the total number of species of arachnid (including spiders, harvestmen and pseudoscorpions) and money spiders (*Linyphiidae*), the most commonly represented family overall, all showing a similar trend of most species in ungrazed and taller swards, and sheep-grazed swards. Eighty-three species were recorded, almost half of which were commonly found across the treatments and are widespread upland species. Fewest species were associated with the sheep and cattle grazed treatments. Total number of individuals of all groups showed a similar trend, and may be because sheep are more likely to avoid patches of tussocky vegetation. Significantly more webs were counted in ungrazed than other treatments in both years. The highest intensity grazing tended to encourage a smaller number of nationally widespread species.

4.76 Dennis *et al.* (2002) [2++] Of six beetle species previously identified as having the highest correlations with each main factor identified from the Principal Component Analysis reported in Dennis (1997) the ground beetles *Carabus problematicus* and *Olophrum piceum* were found to be the species most sensitive to grazing management. Both these species were related to lower grazing intensity, expressed either as taller grass or lower stocking rates. However, *C. problematicus* occurred in *Nardus* grazed by sheep and not by cattle and sheep on the higher slopes, whereas *O. piceum* occurred in taller vegetation that had been ungrazed for two years. The large-scale spatial associations related mainly to landform pattern whereas the smaller ones corresponded to the modification of the vegetation through grazing management, with differences in the sensitivity of beetle species to these factors.

4.77 Littlewood *et al.* (2006c) [2++] found that plant species-richness was greater in grasslands, and differences in composition with heath samples characterised by a number of mosses. Dry grassland sites were the most species-rich. Grass sites typically had higher soil bulk density and pH, and lower loss on Ignition (LOI). Grass samples also had a greater number of *Hemiptera* taxa than heathland, and clear differences in the assemblages of the heath and wet and dry acid grassland samples. Nine taxa were most commonly associated with heath, and 25 taxa most closely associated with grass samples. There is however evidence of a greater degree of specialism in the species found in heathland samples. Plant species accounted for more variance in *Hemipteran* assemblage than other variables, but half of the variation was unexplained. As well as temperature and latitude, loss on ignition and mean vegetation height explained some of the variance. There is broad agreement with other studies that vegetation is the most important factor, with soil explaining further variation. The study suggests that vegetation change and change in associated structure is likely to lead to changes in other aspects of biodiversity, and in this case an increase in Hemipteran diversity. The effects were consistent across a broad range of sites with varying latitude, hydrology and altitude.

4.78 Dennis *et al.* (2008) [1+] found that numbers were unaffected by grazing treatments 6 months after grazing commenced. Significant grazing treatment effects on spiders, bugs and beetles were observed in years 2 and 3, with higher numbers in the low intensity treatments, but no such effect on brachyceran flies, caterpillars and craneflies. Arthropod mass was approximately double in the ungrazed and mixed low intensity treatments compared with commercial sheep grazed treatments. There was a significant response of true bugs, brachyceran flies and overall arthrpod biomass to an interaction of cattle and year in the analysis

4.79 Littlewood *et al.* (2012) [1++] D-vac samples showed grazing treatment had a highly significant effect on *Auchenorrhyncha* abundance and a significant effect on species richness (highest median abundance in ungrazed treatment and lowest in high-intensity sheep grazed). Grazing treatment had significant effect on species assemblage data, and the model explained 42.6% of variation. Sweep-net samples showed the grazing treatment effect on species richness and abundance was not significant, although abundance was highest in the un-grazed plots. The sampling approaches gave broadly similar patterns of abundance and species richness, but differed in the degree to which they were apparent. The two approaches sample different elements of the *Auchenorrhyncha* fauna. Differences in the assemblage between treatments, including between ungrazed and lightly grazed areas, highlight the need for varied grazing regimes to maximise invertebrate biodiversity.

4.80 Littlewood (2008) [1++] found that the overall trend was for higher moth species richness in the light sheep grazed and ungrazed plots. Other studies have shown that *Lepidoptera* are less tolerant of disturbance than are plants. A small number of BAP priority species were, however, found in the heavily grazed plots. They were primarily herbaceous species, which may have fared better than graminiverous species where heavy grazing suppressed grasses. Graminoid feeders were disproportionately well represented in the ungrazed plots, which were characterised by dense grass tussocks. The lightly grazed plots may provide conditions for species with different preferences. The mixed grazing treatment only differed significantly from the ungrazed. This supports other work at the site which did not show a significant interaction of Lepidopteran abundance with cattle grazing, unlike other invertebrate groups.

4.81 Cole *et al.* (2010) [2+] found that year-round grazed plots had a higher relative abundance of smaller invertebrates (for example, small predatory beetle larvae (<10 mm) and small carabids (<9 mm). Summer only grazed sites contained larger predatory beetle larvae (>30 mm), wolf-spiders, harvestmen and larger carabids (>15 mm). For less mobile species, sites with year-round grazing were associated with earthworms, leather jackets and large *Limacidae* slugs (>15 mm), summer-grazed sites were associated with lepidopteran larvae, symphytan larvae and small *Limacidae* slugs and *Arionidae* slugs. Grazing regime tends to be significant at larger spatial scales (>3m) for immobile invertebrate assemblages, with vegetation height and area of fine and broad-leaved grasses at low spatial scales (<1 m). For mobile invertebrate, grazing was most significant at the larger (5 m) spatial scale.

Grazing effects on soils, soil processes and hydrology

4.82 Evans (1977) [2+] showed that grazing-related soil erosion was recorded primarily from *Agrostis-Festuca* swards, which generally held a higher density of sheep, with less in heather moorland and almost none in cotton-grass areas. Regression analysis suggested that bare ground was initiated at stocking densities around 1.8 sheep ha^{-1} (c0.18 LU ha^{-1} yr^{-1}), with summer rates up to twice this. Re-colonisation was observed following a 25-30% reduction in sheep numbers. The study does not differentiate sheep and lambs as Evans (pers comm.) suggests that lambs may have a significant trampling impact. The effective stocking rate in LU terms may therefore be less than indicated here. It is suggested that the threshold of erosion potential is below the livestock carrying capacity, in terms of vegetation productivity, of preferred grasslands.

4.83 Evans (2005) [3+] found that by 2001, thirty-six years after monitoring began, only eight of the original thirty-two scars remained visible. The rate of recolonisation was fastest over the initial ten-year period. At Back Tor expansion continued for longer, although the rate of expansion slowed, with re-colonisation not starting until the peat and organic soil horizons had largely been lost, with an estimated depth of around 450 mm total between the peat and leached horizon below. Estimated loss rate was 13 mm per year. The remaining scars were still used by sheep for shelter and shade. Although Back Tor was subsequently fenced, the reduction in rate of bare ground expansion and subsequent colonisation coincided with reductions in grazing pressure. It is postulated that bare ground is initiated at summer grazing intensities of between 2.5 and 5 sheep ha^{-1} (0.25-0.5 LU ha^{-1}) on short grass and 0.5 sheep ha^{-1} (0.05 LU ha^{-1}) on peat, with a reduction of 30% on these rates allowing recolonisation to start, at least on mineral soils. On eroding peat, recolonisation may not take place until the mineral soil B horizon, which is less acid and more nutrient rich, is exposed. The effects of different stocking rates may on recolonisation may vary with growing season. It is noted that *Calluna* and *Vaccinium* had colonised previously eroded areas, but were absent in *Molinia* dominated areas. Rowan and birch saplings had established in areas of dense heather.

4.84 Anderson & Radford (1994) [2-] showed that stock reductions to low levels below 0.05 LU ha^{-1} yr^{-1} on average (recorded at 0-02 – 0.04 LU ha^{-1} yr^{-1} from counts, compared with previous levels of 0.25 LU ha^{-1} yr^{-1}) allowed vegetation to re-colonise mineral and peaty soil. It was however slow, at least at altitude (c 500m), taking eight years to increase from a mean cover of 49% to 92%. This cover was however achieved in only five years on lower slopes on mineral soil, but much bare ground remained on steep slopes. *Deschampsia flexuosa* spread rapidly from vegetative growth and seed (and biomass increased to six times the initial average biomass after four years), but heather and bilberry continued to spread and the community may change to *Calluna-Vaccinium* in the longer term.

4.85 Bardgett *et al.* (2001) [2+] demonstrated consistent broad scale trends in soil microbial communities along successional gradients that were related to grazing intensity. Microbial biomass was greatest at low to intermediate levels of grazing, and evenness (ie lack of dominance of individual groups) declines as grazing intensity increases. This evidence suggested that decomposer-related processes, such as nutrient cycling, may be optimal at intermediate grazing levels. This was not fully supported by soil respiration rates however, which were highest in lightly grazed treatments at only one site. There was evidence that intensively grazed sites were dominated by bacterial based decomposition, whilst in the lightly grazed or ungrazed treatments fungi have a proportionately greater role. Significant trends in soil C were seen at the Lake District and Snowdonia, being highest in the lightly grazed and short-term ungrazed sites, and lowest in heavily grazed grassland. Soil C:N ratios was influenced by grazing at all locations, being highest in the long-term ungrazed grasslands.

4.86 Garnett *et al.* (2000) [1+] found that after over 30 years of different management there was no detectable difference in the carbon accumulated under the different grazing treatments. Significantly less carbon (C) was contained above the Spheroidal Carbonaceous Particle (SCP) ‘take-off’ point under the treatment which had been burnt every 10 years compared with the unburnt treatment, implying that this management practice contributes to carbon dioxide emissions through decreasing the rate of peat accumulation, stopping peat accumulation and/or reducing C stores by burning existing surface peat. It was not possible to establish which of these processes dominated at this site. The stocking rates at the site are quoted as the equivalent of 0.002 – 0.016 LU ha^{-1} yr^{-1}, which is low and affects the likelihood of detecting a grazing effect.

4.87 Ward *et al.* (2007) [1+] showed grazing to significantly affect above ground C storage, reducing it by 22% in light summer grazed plots compared with ungrazed. This was attributed to the greater biomass of C-rich shrubs relative to graminoids. Grazing however increased the rates of respiration and photosynthesis relative to ungrazed treatments, but to a lesser extent than burning. Grazed plots acted as a greater net sink for carbon dioxide (CO_2) than ungrazed plots over 10 of the 15 dates sampled. The results suggest that long term disturbance from burning and grazing increased ecosystem processes and gross CO_2 fluxes, and reduced net efflux. Grazing significantly increased methane (CH_4) effluxes at all sample dates compared with ungrazed, and with greater effect than burning, although the reasons remain unclear. The lowest fluxes occurred in the ungrazed, unburned plots. Dissolved organic carbon (DOC) was only affected by grazing, with greater concentrations at 10 cm depth compared to ungrazed. The effect was small, and mechanisms unclear. The findings indicated that release of DOC was controlled by climate rather than land use. There was no detectable effect on soil microbial processes such as N mineralisation.

4.88 Medina-Roldán *et al.* (2012) [2+] found that grazing exclusion increased the relative abundance of dwarf shrub and reduced the proportion of graminoids. It also increased the litter layer dry weight by 70%, which may be a result of the greater contribution from woody dwarf shrub and the slower decomposition of this material, and greater accumulation of dead material. Root biomass varied seasonally, but there was no grazing effect. Other organic horizons were not affected by grazing or season. Grazing removal was associated with a 20% reduction in microbial activity and a 30% decrease in microbial biomass N. Net ammonia mineralisation was lower in the ungrazed area as was the ratio of dissolved organic to inorganic N, which is consistent with a decrease in ecosystem productivity. The slowing down of nutrient cycling may be related to reduced dung inputs, and changes in the character of plant litter. Grazing exclusion was shown not to affect water table depth, so soil moisture was not a significant driver of differences in nutrient cycling. Despite slowing of N cycling and build up of litter, grazing exclusion did not increase C or N in soil. This adds to other evidence of lack of response to grazing removal, even after 30 years (Garnett *et al.* 2000; Ward *et al.* 2007) Grazing exclusion did not modify other soil properties including DOC, DON and microbial C, which showed stronger seasonal variation than between grazing treatments.

4.89 Worrall *et al.* (2007) [1-] found a significant effect of grazing on depth to water table but little evidence of effect on other parameters measured. Water tables were shallower (ie nearer the surface) with grazing, said to be due to reduced vegetation development. There was no significant interaction between grazing and burning. Whilst there were no significant grazing effects on water quality parameters, there were some significant interactions, with grazing appearing to enhance the effect of frequent burning in reducing conductivity and DOC. The results do not necessarily mean that peat development is greater or DOC export less on more intensively managed plots as there may be reduced presence of peat-forming plants and DOC loss may be greater through other pathways, such as surface runoff.

4.90 Worrall *et al.* (2008) [1-] found that on burned treatments there was a significant decline in Ca, Mg, Na and phosphate. The only increase post burning was for Al on the 10 year burn sites, where there was also a significantly lower pH. Only chloride showed a significant change (decrease) with the presence of grazing and then only in conjunction with burning. There was no evidence of soil structural changes from long-term burning and grazing.

4.91 Clay *et al.* (2009) [1-] found that water tables were closest to the surface on 20 year burn/grazed plots and deepest on plots that had never been burnt (in contrast to Worrall (2007) who found that water tables were closest to the surface in the 10-year burn/grazed plots). In the ten-year burning plots the water tables were significantly shallower following burning than before. Hydraulic conductivity, as determined by dipwell slug tests, was significantly lower on 20 year burn plots. Overall, the effect of grazing was to reduce the depth to water table by 25%. Runoff occurred at a significantly greater frequency on sites that had recently been burnt, grazing had no detectable effect on run-off. These variations in hydrological response will have important consequences in DOC export through changes in water table and the partitioning of precipitation into runoff.

5 What methods of stocking rate calculation, or setting grazing regimes, consistently provide regimes that maintain or restore moorland biodiversity and what are the key parameters that calculations should include?

Introduction

5.1 The main mechanism employed for limiting adverse grazing impacts and securing improvements in condition through agri-environment schemes is the setting of maximum stocking rates. The stocking rates applied under conservation grazing regimes and a summary of how the approach has evolved is summarized in the introduction and appendices. The limitations of a prescriptive approach in setting stocking rates, especially as they are usually part of a 5 or 10-year agreement, has been well recognised (for example, Ecoscope 2003). Whilst more recent approaches have included greater flexibility to take account of different vegetation types and proportions on a grazing unit, and allow for greater variation across the year, there is still criticism from stakeholders that the approach does not adequately take account of site-specific conditions and variation in growing conditions between seasons. However, there are some benefits of a standardised approach that can be implemented consistently within the resources available to set up and monitor a farm agreement. To this end, even if there is flexibility to develop site--specific regimes, it is useful to have some knowledge of an initial level of grazing that is likely to deliver key habitat objectives. Knowledge of the typical annual biomass production of different moorland vegetation types is the basis of developing sustainable grazing regimes, along with the level of biomass removal that can be sustained without affecting growth. Some studies attempt to identify an annual average stocking rate that sustains key species, usually heather.

Summary of evidence

5.2 There is moderate evidence Hulme *et al.* (1999) [1+] that productivity of *Agrostis-Fescue* grassland can vary markedly, and consistently, between sites of different soil fertility. There is weak evidence from Milne *et al.* (2002) [2+] that annual biomass production of different heather growth phases and *Nardus* grassland varies with weather effects, and therefore geographically, and that the productivity of *Molinia* varies significantly between years Fraser *et al.* (2011) [2+].

5.3 There is weak evidence Kirkham & Milne (2002) [2+] that a grazing index of up to 40% may sustain older heather, but this represents the upper threshold above which young heather growth is suppressed. There is strong evidence Pakeman (2003) [1+]; Pakeman & Nolan (2009) [1++] that a utilization level of 20% provides a widely applicable utilization threshold for maintaining heather cover. There is moderate evidence from Poulton (2011) [1++] that setting stocking rate limits that take account of proportion of different vegetation types in a grazing unit can reduce the impacts on dwarf shrub.

5.4 Hulme *et al.* (2002) [2++]; Pakeman *et al.* (2003) [1+] provide strong evidence that in most cases an average annual sheep stocking rates of under 1 ewe $ha^{-1}yr^{-1}$ is likely to improve heather condition in mosaics of heather and grasses. While increasing stocking rates may be associated with increased heather defoliation Oom *et al.* (2010) [2+]; Hulme *et al.* (2002) [2++] there is moderate evidence that utilisation of *Calluna* is not proportional to the sheep numbers grazing, as sheep primarily select grassland elements and there is strong evidence that measuring the utilisation of key sward components, and particularly those that are most closely linked to management objectives, gives a better basis for setting grazing management than stock numbers Pakeman *et al.* (2003) [1+]; Pakeman & Nolan (2009) [1++].

5.5 There is strong evidence that grazing can reduce *Molinia* cover, but that the impact of target levels of *Molinia* utilisation varies depending on species of grazer and the site Grant *et al.* (1996a) [2+]; Critchley *et al.* (2008) [2-]; Fraser *et al.* (2011) [2+]; Ross (2000) [2-]. There is moderate evidence that a grazing level which achieves 33% utilisation of the annual leaf growth can reduce *Molinia* biomass, increase floristic diversity and allow heather regeneration Grant *et al.* (1996a) [2+]; Ross (2000) [2-], whereas a higher utilisation rate of 66% may compromise heather regeneration Ross (2000) [2-]. However, it has also been reported that annual *Molinia* cover has continued to increase when summer grazing is set to 50% utilisation Fraser *et al.* (2011) [2+]. There is weak evidence that the effect of grazing in combination with other restoration treatments may be more positive on *Molinia-Calluna* sites than *Molinia* sites Marrs *et al.* (2004) [2+].

Analysis and evidence statements

Biomass production

5.6 Milne *et al.* 2002 [2+] found there was a significant effect of year on current season's growth for each heather phase. There was also a significant effect of region, with the south west having the lowest biomass of current season's growth. Contrary to expectation, the older growth phases had significantly greater seasonal biomass production than young phases. The mean biomass productivity of different heather growth phases was found to be higher than previous Scottish-based studies (for example, Grant *et al.* 1982), which may have implications for the actual amount of off-take required to achieve suppressive levels of utilization, and is likely to affect the carrying capacity of heather before heather growth is suppressed. Alternatively, increased productivity could lead to a rapid increase in the woody portion, making plants more susceptible to grazing. There was no significant effect of region or year on live annual biomass production of *Vaccinium myrtillus*, or *Agrostis-Festuca* grassland. *Nardus* biomass production was however significantly lower in 1995 than other years, and lower in the North Pennines, reflecting the significant relationship found with mean monthly maximum temperature, and possibly the previous heavy grazing pressure.

5.7 Hulme *et al.* (1999) [1+] demonstrated that sheep grazing days required to achieve the sward height treatments (3 cm, 4.5 cm, 6 cm) on the more productive *Agrostis-Festuca* community over brown earth were typically 2-3 times greater than required at the podzolic site.

5.8 Fraser *et al.* (2011) [2+] showed that the number of grazing days required to achieve the target *Molinia* utilisation level varied from 49 to 76, reflecting the variation in growing conditions between seasons. *Molinia* cover and biomass was reduced during the grazing season by cattle grazing. The increase in cover in the sheep grazed plots was half that of the ungrazed plots whilst biomass was also less in the sheep grazed plots than the ungrazed plots. Significant time effects were identified with regards to pre-grazing period cover of *Molinia* (increase), broad-leaved grasses (increase), fine-leaved grasses (decrease) and dwarf shrub (decrease) over the study period. There were significant effects over time on post-grazing cover of *Molinia* (increase), *Nardus* (increase) and dwarf shrub (decrease). Treatment type had little effect on sward composition year on year, with only *Molinia* showing a significant change (increase) both before and after grazing.

Grazing utilisation of *Molinia*

5.9 Grant *et al.* (1996a) [2+] demonstrated that six years of grazing by cattle to remove 33% and 66% of annual growth resulted in reductions in *Molinia* biomass by 46-65% and 86% compared to ungrazed, under the low and high defoliation rates respectively. Floristic diversity increased in grazed plots, primarily through increased cover of other broad-leafed grasses.

5.10 Critchley *et al.* (2008) [2-] showed that in mixed grazing paddocks (sheep with summer cattle) *Molinia* cover declined substantially where it had previously been abundant. *Calluna* also declined slightly, primarily because of localised trampling. *Molinia* cover increased in the sheep-only paddocks and *Calluna* cover declined slightly despite low grazing indices, although there was a significant increase in frequency in the low sheep treatment.

5.11 Ross (2000) [2-] found that summer-only grazing by sheep was effective in controlling *Molinia* in the three years following burning. A grazing level set to remove approximately 33% of the annual leaf growth was effective at reducing cover whilst allowing heather seedling regeneration. The higher utilization rate of 66% compromised heather regeneration.

Effects of stocking rates and heather utilisation

5.12 Hulme *et al.* (2002) [2++] found that utilisation in all grazed treatments was within the range in which heather is thought to be able to maintain its growth, and resulted in similar responses in height and frequency increase between treatments. Reduction in utilisation was not proportional to sheep number reductions, and was greatest in summer-only grazing when palatable grass growth is at a maximum. Lack of summer grazing allowed *Molinia* to thrive, even though heather utilisation was low enough not to affect growth of this species. Summer grazing kept *Molinia* in check, whilst exclosure (ungrazed) increased the competition from heather. From the experiment a stocking rate of between 0.7 sheep ha^{-1} and 1.4 sheep ha^{-1} in a year-round grazing regime increased the vigour of previously heavily grazed heather on wet heath, for the proportions of heather and grass at the study site, whilst a rate of 2.1 sheep ha^{-1} resulted in continued degradation.

5.13 Pakeman *et al.* (2003) [1+] found that on the dry heath system studied a reduction in sheep numbers to 0.8/0.9 sheep ha^{-1} yr^{-1} to give utilisation levels below 20% was seen to achieve the desired result of improving vegetation condition, for the proportions of heather and grass at the study site. There was little effect of timing of grazing. It is suggested however that measured utilisation of heather provides a better basis for setting grazing management than sheep numbers. There was some heather recovery under all treatments (low and high rates applied in each of winter and summer) which were reductions on the control. Utilisation rates declined as heather increased. Rabbits were shown to have a measurable negative effect on heather recovery.

5.14 Pakeman & Nolan (2009) [1++] from an analysis of ten controlled grazing experiments found that a utilization level of 31.6% of current season's growth was found to maintain the balance between heather and monocots. However the 95% confidence intervals for no change are 22.5% and 41.4%, indicating a considerable degree of variation and uncertainty. The previously assumed sustainable heather shoot utilization level of 40% may be too high and it was recommended it should be set nearer 20% to reduce the risk of heather loss (where this is an objective). This represented the lower end of the range of utilisation rates associated with no change across the sites studied. Whilst the relationship between stocking rate and percentage utilisation was strong, with an increase of 15.1% for each 1 sheep ha^{-1} yr^{-1}, it was suggested that developing models based on utilisation data is more efficient and robust than using stocking rate, which needs to take more account of the proportions of different vegetation types.

5.15 Kirkham & Milne (2000) [2+] showed there was considerable variation in the relationship between grazing index (GI) and both shoot growth and differential (grazed vs ungrazed) productivity. Contrary to expectations, pioneer heather was apparently less tolerant of grazing pressure than mature heather. The models suggested a stimulation of shoot growth on mature heather at low grazing pressure (<0.4 GI), and suppression at high, consistent with predictions of Palmer (1997). However, the model was dependant on very few data points at higher GI levels. Pioneer heather showed a linear response of suppression with increasing grazing intensity. The apparent difference in susceptibility between pioneer and mature heather was supported by data for woody growth, variation in which may reflect differences in grazing pressure over a number of years. Across the whole data set heather shoot growth showed a positive correlation with weights of woody material. For mature heather it appeared that the largest and most productive plants tend to result from intermediate levels of grazing, but no such relationship was observed in young heather. In conclusion it was tentatively suggested that a grazing index of 0.4 may be optimum for mature heather, and tentatively suggested that this might represent a threshold for pioneer heather in some circumstances.

5.16 Poulton (2011) [1++] in a meta-analysis of a large number of surveys of sites subject to stock reductions to limit overgrazing (see stocking rates, appendix 3), but not intended to significantly enhance condition, showed highly significant declines over time in surrogate measures of grazing pressure. Incidence of livestock dung declined and heather grazing index declined from a mean of 60% in 2000 to 40% in 2008. The proportion of heather displaying suppresses growth forms declined. There was however no significant change in cover and abundance of species or groups, but a significant decrease in bare ground. The findings suggest that overall the implemented stocking rates achieve the desired outcome of reducing detrimental grazing impacts on heather.

6 What changes have taken place under recent reductions and seasonal changes in sheep grazing and what is the significance of these changes?

Introduction

6.1 Experimental studies can provide some evidence for the effects of reduced and seasonal grazing compared to more typical rates. Controlled grazing experiments are however usually small scale and for a limited duration, and likely to involve non-breeding animals. Whilst such studies have greatly improved our understanding of how animals graze, small plots cannot replicate the scale and heterogeneity of large grazing units, and the increased spatial variation in grazing pressure that is likely to occur. As stock numbers have been reduced or grazing regimes altered in upland areas it is necessary to understand what the effects are, and how effective advice based on experimental studies is in delivering grazing objectives at the moorland unit scale. This section includes some evidence from site-specific monitoring studies, and also some observational evidence. However, there is a general lack of detailed monitoring at appropriate scales to detect the response of different components of a moorland unit to reduced grazing. The generalised findings from earlier ESA monitoring, largely focussed on heather moorland, and which highlighted the need for a more site-specific approach, is summarized under Historical context in Chapter 1 and Appendix 1.

Summary of evidence of the effects of stock reductions and seasonal changes

6.2 There is weak evidence Miller *et al.* (1999) [2+] that removing or reducing summer grazing can benefit the survival of annual plant species, but in the medium-long term can reduce populations through loss of bare ground.

6.3 There is weak evidence Uff (2011) [2+] that ESA stocking rates can significantly improve the condition of *Calluna* in dry heath over a 15 year period. However there is moderate evidence Uff (2011) [2+]; Hope *et al.* (1996) [2+] that there may be no significant expansion of heathland vegetation under ESA-type stocking rates over periods of 10-15 years, particularly where graminoids such as *Molinia* respond positively to reduced grazing pressure.

6.4 There is moderate evidence Miller *et al.* (2010) [2+]; Martin (2010) [2+] that bryophyte cover can increase in high altitude habitats over a 10 year period with reduced grazing, at the expense of bare ground (which can provide regeneration niches) and grasses.

6.5 There is moderate evidence Martin (2010) [2+]; Webb (2012) [3+]; Johnston (2012) [3+] that stock reductions to annual averages of around 0.5 ewes ha^{-1} or less have resulted in improvements in low-productivity upland habitats over periods of around 10 years.

Analysis and evidence statements

6.6 Hope *et al.* (1996) [2+] found reduced sheep grazing was shown to quickly result in taller vegetation, with few apparent changes in floristic composition. Patches of dwarf shrub-dominated vegetation tended to be larger and grassland smaller where sheep had been reduced in western and some northern sites. Vole activity was shown to increase as grass height increased above 5 cm. Grazing by red deer and continued heather burning limited the change in many sites.

6.7 Miller *et al.* (1999) [2+] found that vegetation height increased in the summer ungrazed plots (by 50-60 mm), but not in the grazed plots, and the cover of bare ground decreased in the ungrazed plots but not in the grazed plots. Gentians in the ungrazed plots grew taller and survived better (<10% mortality compared to 30-50%) over a growing season than did plants in adjacent grazed plots. Gentian numbers fluctuated more on the grazed plots than the ungrazed plots, but from the fourth year of summer grazing protection the number of gentians declined significantly more in the ungrazed plots. The strong correlation of gentian number with bare ground cover the previous autumn in the ungrazed plots shows the importance of bare ground for this annual plant's reproduction. The results suggest that around about 4% cover is needed. The results suggest it should be possible (if not practical on Ben Lawers) to manipulate the stocking rate to maximise the gentian population.

6.8 Martin (2010) [2+] Showed that over eight years of reduced grazing on Cross Fell plateau, the proportion of sample points dominated by *Carex bigelowii* increased to 52% of quadrats from 14% in 2003, at the expense of *Festuca* ovina. The mean height of all species including *Vaccinium*, *Carex bigelowii* and mosses increased significantly, with the average graminoid height more than doubling to 6.5 cm. Average moss and lichen cover also doubled to 27% from 13%. There was no positive response in lichen species, with declines in some, which may be related to increased competition and shading. The overall trend was for decreasing grass dominance and increased similarity to montane sedge and moss-heath vegetation.

6.9 Miller *et al.* (2010) [2+] found that excluding sheep caused major shifts in the balance amongst species over ten years. The vegetation composition and structure of grazed plots did not change significantly over the course of the experiment, but in the summer-ungrazed plots bryophyte and litter cover increased whilst bare ground decreased. The cover of graminoids and some forbs increased in the middle years of the experiment before declining back towards the baseline level by the end of the experiment.

6.10 Uff (2011) [2+] reports that the condition of existing heather on the Long Mynd common has improved with sheep reductions to 1.5 ewes ha^{-1} in summer and 0.75 ewes ha^{-1} in winter, but to date there has not been significant increases in heather area. Mean heather grazing index has declined to less than 15% and flowering has increased. The proportion of heather assessed as in 'poor' condition, based on a number of variables, declined from 60% in 1998 to less than 10% in 2011.

6.11 Webb (2012) [3+] reported that a significant reduction in sheep grazing to an annual average of around 0.5 ewes per ha with no winter grazing had allowed a number of montane plants, which were previously suppressed, to flower. This was through a combination of reduced spring grazing and lack of winter grazing allowing over-wintered buds to survive. Grazing pressure on preferred cliff ledge communities had reduced, although were still selectively grazed in more accessible areas. Vegetation structure had become more variable at a range of scales, with the tallest vegetation generally on the more productive lower slopes.

6.12 Johnston (2012) [3+] from an exercise to collate stocking rate and condition monitoring data from a number of grazing units in the Lake District high fells indicated that annual average stocking rates of , 0.02-0.07 LU ha^{-1} yr^{-1} had resulted in improvement in habitat condition over a period of around 10 years. Blanket bog had responded well where annual average rates were below 0.03 LU ha^{-1} yr^{-1}, often through off-wintering. The response of other sensitive habitats such as ledge and montane communities was more variable. These were often small areas within grassy fells which could otherwise accommodate higher stocking rates. Stock reduction tended to promote patchy grazing, with avoidance of less palatable species.

7 Over what timescales can grazing-related change in plant structure and diversity be observed or expected?

Introduction

7.1 The search terms used failed to identify references specifically relating to timescales of change. The focus of research is usually on mechanisms and direction of change, with a definite end-point rarely specified. In addition, research projects are often funded for relatively short periods of time. There is however some evidence from studies reported under other sub-questions, particularly from sites where there has been continuity of research, although the focus and objectives of the research may have changed over time. Repeat monitoring studies can also provide an indication of rates and direction of change, though the findings of agri-environment monitoring have usually been generalised across a number of sites, and again often provides only limited information on timescales of change.

Summary of evidence for timescales of grazing-related change

7.2 There is strong evidence that successional change of most typical upland vegetation types is slow, as long-term grazing exclusion (>30 years) at a number of sites has not resulted in succession to scrub or woodland Hill *et al.* (1992) [2++]; Adamson & Kahl (2003) [2+]; Fryday (2001) [2-].

7.3 There is weak evidence Hulme *et al.* (1999) [1+]; that acid grasslands can be very stable, and change little under different grazing regimes over periods of several years.

7.4 There is moderate evidence Welch *et al.* (2005) [2+]; Britton *et al.* (2005) [2-] that montane heath can degrade rapidly, over a period of 5 or 6 years, with increased grazing pressure. Martin (2010) [2+] provided weak evidence that, where key species are still present, some restoration can take place over a ten-year period with light grazing. However, this may not be the case under severe degradation, where the organic soil layer has been lost Britton *et al.* (2005) [2-].

7.5 There is weak evidence Gardner *et al.* (2002) [2+]; Critchley *et al.* (2008) [2-] that reduced grazing to agri-environment rates, including cattle grazing, may not result in expansion of heathland.

7.6 Mitchell *et al.* (2008) [2++]; Critchley *et al.* (in press): demonstrated that heathland restoration with disturbance, seed introduction and grazing exclusion or low intensity cattle grazing resulted in heather cover of 20%-30% after 8 years. (CSM favourable condition target is 50% cover.)

7.7 There is strong evidence Calladine *et al.* (2002) [2+]; Dennis *et al.* (2001) [1+]; Evans *et al.* (2006b) [1+]; Dennis *et al.* (2008) [1+]; Littlewood (2008) [1++]; Douglas *et al.* (2008)[2-] that abundance of some moorland bird, mammal and invertebrate species and groups can respond quickly (2-5 years) to changes in grazing regime.

The evidence for timescales of grazing-related change

Grazing removal

7.8 Hill *et al.* (1992) [2++] found that *Agrostis-Festuca* grasslands on brown earths changed less than more 'heathy' grasslands on podzolic soils where *Deschampsia fexuosa*, *Molinia* or ericoids became more prominent at the expense of *Nardus*, sheep's fescue and heath rush and other low-growing plants. Few new species appeared other than broad buckler-fern on grass litter and rowan along fence lines. Almost all change occurred through clonal spread or growth of individuals. Peaks in vole abundance resulted in dead grass and moss, but no bare ground. They are also contributors to variation in biomass, in the absence of sheep.

7.9 Fryday (2001) [2-] found that removal of grazing increased the cover and biomass of fruticose lichens, although the effect may be less at higher altitude. Lichen diversity was generally reduced by grazing exclusion, with diversity inversely related to vascular plant height, but again this effect reduced with altitude. Development of a dense vegetation mat was seen to mask the effects of limestone substrates and resulted in the development of a lichen flora similar to acidic conditions. Whist there was some evidence in increase in dwarf shrub species in protected plots, and increased herb cover on high level limestone grassland, the grazed and ungrazed plots were recognisably similar.

7.10 Adamson & Kahl (2003)[2+] updated findings from ten long-term grazing exclusion plots (30-46 years), which were re-surveyed to assess change. The rate of change varied between sites but was generally slow. Lower altitude grassland sites generally showed declines in *Nardus*, *Festuca ovina* and dramatic declines in *Juncus squarrosus*. These changes have been accompanied by a noticeable increase in herb species. At high altitude grassland sites (also reported in Welch & Rawes 1964) *Deschampsia flexuosa* and *Carex bigelowii* increased at the expense of the same dominant graminoids. There were marked changes in high altitude bog vegetation with grazing exclusion. These changes included *Calluna* establishment above the typical upper limit outside the exclosures, and increases in *Empetrum nigrum*, *Rubus chaemaemorus* and *Narthecium ossifragum* (see also Rawes, 1983). Lower altitude bog was in an area of low grazing pressure and high heather cover, where observed response to stock exclusion has been small (Rawes & Hobbs, 1979). Biomass increased at all sites. Moss cover generally declined, but lichens increased which may be down to reduced trampling. The low frequency of *Calluna* on one blanket bog site after 31 years emphasized the slow rate of change and long timescales likely to be required for vegetation to reach a new equilibrium.

Controlled grazing studies

7.11 Hulme *et al.* (1999) [1+] found that in height treatments (3 cm, 4.5 cm, 6 cm) on the more productive community over brown earth were typically 2-3 times that required at the podzolic site. There was little overall change in composition over 7 years. The heavy grazing (low sward height) treatment at the low productivity site allowed *Nardus* to spread, and resulted in an increase in moss at the productive site, where *Nardus* was absent. Least change was associated with 4.5 cm treatment at the productive and 6 cm at the moorland site.

7.12 Gardner *et al.* (2002) [2+] reported a range of experiments to investigate the effect of stocking rate, seasonal grazing and spatial grazing patterns on the recovery of dwarf heath communities. There was little change in top cover of species in *Calluna*-*Nardus* at the ESA tier 1 stocking rate, although there was a decrease in top cover of *Calluna* in this vegetation under tier 2 rates, related to increased cover of other species. On the whole vegetation remained stable across the plots.

7.13 Critchley *et al.* (2008) [2-] showed that in mixed grazing paddocks (sheep with summer cattle) *Molinia* cover declined substantially where it had previously been abundant. *Calluna* also declined slightly, primarily because of localised trampling. *Molinia* cover increased in the sheep-only paddocks and *Calluna* cover declined slightly despite low grazing indices, although there was a significant increase in frequency in the low sheep treatment. Other changes in plant community composition were minor. There was no evidence of a significant move towards wet heath communities after 4 years.

7.14 Mitchell *et al.* (2008) [2++] showed that heather established successfully when introduced from seed on grass-dominated moorlands, also critical was the amount of bare ground, rather than the methods of creation (mechanical vs trampling). When the disturbance intensity was low and little bare ground was created, low intensity grazing increased *Calluna* occurrence. After a further four years Critchley *et al.* (in press) found that grazing exclusion and cattle grazing had a significant effect on heather morphology, with significantly greater height, number of shoots and dry weight than in either the sheep only or mixed grazing plots. Heather cover was highest in seeded and rotovated or trampled plots protected from grazing (25-30% cover), and next highest in the same combination of treatments where cattle only grazed (20-25%).

Monitoring and observational studies

7.15 Welch *et al.* (2005) [2+] found that altering the grazing patterns of free-ranging stock through, in this case, the provision of shelter, has resulted in a significant reduction in key moss heath species and increased cover of grass in the 15 m zone adjacent to the fence. It would appear that the balance of *Racomitrium* and grass changed rapidly before monitoring commenced (6 years from erection of fence).

7.16 Britton *et al.* (2005) [2-] found it likely that habitat degradation of montane heath occurred rapidly in early years of increased grazing (see Welch, 2005 – loss of *Racomitrium* in response to increased grazing pressure). Degradation is likely to be on-going at this site however, as dung counts suggested high grazing pressure. Overall the results show that the organic horizon has been lost under the most severely degraded vegetation, so physical and chemical conditions are likely to be unfavourable for re-colonisation and species restoration is likely to be very slow.

7.17 Martin (2010) [2+] showed that over eight years of reduced grazing on Cross Fell plateau, the proportion of sample points dominated by *Carex bigelowii* increased to 52% of quadrats from 14% in 2003, at the expense of *Festuca ovina*. The mean height of all species including *Vaccinium myrtillus*, *Carex bigelowii* and mosses increased significantly, with the average graminoid height more than doubling to 6.5 cm. Average moss and lichen cover also doubled to 27% from 13%. There was no positive response in lichen species, with declines in some, which may be related to increased competition and shading. The overall trend was for decreasing grass dominance and increased similarity to montane sedge and moss-heath vegetation.

8 How is ‘under-grazing’ defined? What are the effects of low intensity regimes, set to restore small areas of priority habitat within a moorland mosaic, on other parts of the moorland including non-target habitats such as acid grassland?

8.1 This has proved the most difficult sub-topic to address from the scientific literature. A definition or view of what constitutes under-grazing is dependent on objectives and what the grazing management of the site is intended to achieve. Taller swards resulting from reduced grazing pressure aimed at restoring dwarf shrub and other habitat components is often viewed by farmers as a sign of under-grazing, although there may be an accompanying increase in preferred grasses. An increase in the cover and dominance of competitive species can result in reduced species diversity and a reduction or loss of less-competitive low growing species in particular, which could be detrimental in terms of biodiversity objectives. It may however be a necessary compromise in seeking to restore particular species or groups, or other ecosystem benefits.

8.2 Whilst there is a requirement not to overgraze attached to farm support payments under CAP, there is no similar requirement to avoid under-grazing, although there is a general cross-compliance requirement to maintain land not in agricultural production, including no longer grazed, in good agricultural and environmental condition (GAEC 12). This requires only sporadic (once in 5 year) cutting or grazing management, unless this conflicts with other conservation objectives for the site. Good Farming Practice (GFP) attached to schemes under the England Rural Development Programme (pre-2007) included a requirement not to under-graze, but no definition or test was developed, in contrast to the situation with overgrazing.

8.3 The searches did not identify any evidence sources that attempted to define under-grazing, at least from the perspective of this topic review. Sources identified under other sub-topics do however provide evidence for when desired biodiversity outcomes may be hindered by grazing that is too light. This is explored further in Chapter 13.

9 What factors influence the spatial pattern of grazing? How effective are tools such as shepherding and burning in influencing grazing distribution, and how do they interact with stocking rates to achieve improvements in habitat condition and ecosystem services?

Introduction

9.1 The spatial distribution and the pattern of movement of grazing animals is an important factor in determining the impacts and effects of grazing. This is potentially influenced by a large range of factors operating at a range of scales, including dietary requirements, vegetation composition, digestibility and availability, weather and land and livestock management techniques. There are a number of studies that provide evidence for the effect of the distribution and proximity of different vegetation types on spatial grazing patterns. There are few scientific studies of the effects of livestock management practices such as shepherding. Two studies consider the effect of hefting, or how livestock mangers use aspects of sheep behaviour and home-ranging within management systems to control the area grazed by a flock, without the need for fencing on shared grazing, such as common land.

Summary of evidence for spatial factors that influence grazing patterns

9.2 There is strong evidence from Palmer *et al.* (2003) [2+]; Oom *et al.* (2008) [2+]; Oom *et al.* (2010) [2+]; Hetherington (2002) [1+]; Williams *et al.* (2011) [2+]; Welch (1984 a,b) [2-]; Clarke *et al.* (1995a, 1995b) [2-, 2-]; Hester & Bailie (1998)[2-]; Hester *et al.* (1999) [2-] that the spatial impacts of grazing on heather are influenced by the size and distribution of grass patches, with greatest impact in the heather zone closest to grass. There is moderate evidence Oom *et al.* (2010) [2+]; Clarke *et al.* (1995a, 1995b) [2-, 2-]; Hester & Bailie (1998)[2-] that the overall extent of detrimental grazing impact on dwarf shrub is a function of spatial distribution of preferred grasses, and overall stocking rate. There is weak evidence of a significant linear relationships between heather defoliation rate and the decrease in shrub vegetation/increase in mixed vegetation associated with adjacent grass patches Oom *et al.* (2008) [2+].

9.3 There is weak evidence Palmer *et al.* (2003) [2+] that impact on adjacent heather is greatest around the most preferred grass types, and strong evidence that reductions in the availability of preferred food items can lead to the condition and regeneration of *Calluna* being compromised Grant *et al.* (1985) [2+], Cooper *et al.* (1997) [2++], Ross (2009) [2-]; with weak evidence that utilization of heather increases in autumn Hester & Bailie (1998)[2-]; Hester *et al.* (1999) [2-].

9.4 There is weak evidence Sibbald *et al.* (2008) [2+] that sheep prefer to graze on large grass areas than smaller patches, and this may reflect their grouping behaviour, ie choosing to graze together, however there is also weak evidence Hester & Baillie (1998) [2-]; Hester *et al.* (1999) [2-] that sheep prefer small grass patches.

9.5 There is moderate evidence Oom *et al.* (2008) [2+]; Oom *et al.* (2010) [2+]; Hester *et al.* (1999) [2-] that sheep will tend to lie up and dung on grass patches, and moderate evidence that heather utilization is highest on the uphill edge of patches Hester & Baillie (1998) [2-]; Oom *et al.* (2010) [2+]. There is weak evidence Oom *et al.* (2008) [2+] that sheep resting areas influence spatial patterns of vegetation change, causing a greater degree of aggregation of grass expansion than through grazing alone. There is weak evidence Clarke *et al.* (1995a, 1995b) [2-, 2-]; Hester *et al.* (1999) [2-] that the time sheep spend grazing grass and heather will strongly influence the degree of vegetation fragmentation, but not the time spent by deer.

9.6 There is weak evidence Grant & Hunter (1968) [2+]; Grant (1968) [2-] that sheep may graze short heather on re-colonising burned areas in preference to taller heather.

9.7 There is moderate evidence that localised grazing patterns can be altered by provision of infrastructure such as shelter or water Welch *et al.* (2005) [2+], Jewel *et al.* (2005) [2-].

9.8 Hunter & Milner (1963) [2+]; Lawrence & Wood-Gush (1998) [2+] provide moderate evidence of home-range faithfulness in sheep, with the effects stronger in older sheep. There is moderate evidence from these studies that sheep disperse more in summer and cluster more in winter. There is weak evidence Hunter & Milner (1963) [2+] that an individual sheep's ranging behaviour, and therefore diet, is strongly influenced by its mother. There is weak evidence Williams *et al.* (2011) [2+] of seasonal differences in vegetation patch selection, but of uneven use of the grazing unit overall.

9.9 There is weak evidence from Hunter & Milner (1963) [2+] that home-ranging behaviour is not substantially affected by shepherding or supplementary feeding. There is moderate evidence Hetherington (2000) [1+] that feed blocks can be used to alter sheep grazing patterns and encourage sheep to graze less preferred species, but it may have greatest influence on sheep of the closest home-range Hunter & Milner (1963) [2+].

9.10 There is weak evidence Hester & Baillie (1998) [2-]; Hester *et al.* (1999) [2-] that the grazing impact of deer on heather is likely to be greater around large patches, but their distribution is less influenced by heather fragmentation.

Analysis and evidence statements

Vegetation pattern

9.11 Welch (1984 a, b) [2-] found that the factors which most influenced grazing animal of a sample area occupance were nearness to improved grasslands or swards containing preferred graminoids, and the role of each moorland tract in the management of the farm to which it belonged. Heather declined under heavier grazing and increased mainly at sites receiving little dung.

9.12 Clarke *et al.* (1995a, 1995b) [2-, 2-] found that size and distribution of grass patches in dwarf shrub heath influences animal distribution and grazing pressure. Selection of grass over heather during daytime grazing was strong, but the size and distribution of grass patches significantly affected the grazing time spent on heather by sheep but not deer. Sheep graze in smaller groups and spend more time in heather where there are many small grass patches compared to few large patches. Sheep density on heather and heather utilisation was found to be highest in a zone of up to 5 m around grass, dropping to background levels beyond this. Increased fragmentation of grass can therefore lead to increased grazing on heather, and potentially damaging utilisation rates at high sheep numbers, over a wider area than the same area of grass concentrated in fewer large patches.

9.13 Hester & Baillie (1998) [2-] found that *Calluna* utilisation by both sheep and deer was greatest in proximity to grassland, and more fragmented vegetation therefore showed a greater proportion of *Calluna* use. The rate of decline in utilization with distance from grass was similar with differing utilisation, so when utilisation was heaviest (autumn grazing) it was seen to decline to background levels within 3 m of the grassland edge, and within 1 m of the grassland edge in years with lower overall utilization. Autumn grazing impact on *Calluna* by both species was heavier as the grazing value of grassland declined. Sheep and deer appeared to consume similar amounts of *Calluna* during summer, but autumn utilisation by deer was greater than sheep (the experiments did not look at winter utilisation), therefore autumn grazing by deer may be more damaging than sheep. At the stocking rates applied, utilisation only exceeded 40% in the autumn grazed year. Sheep were found to prefer smaller patches of grass whilst deer prefer larger ones, or are less selective. Thus the impact on a grass heath mosaic varies with type of grazing animal, with greater impact from deer around large grass patches as the ratio of edge to area is reduced, and no consistent difference with sheep. Little *Calluna* was grazed on the downslope edge of patches as animals tend to face uphill. Impact around paths was very noticeable with sheep. Trampling activity and impact due to lying down can be significant in *Calluna* loss. At low grazing levels trampling impact can be greater than herbivory, especially on sloping ground.

9.14 Hester *et al.* (1999) [2-] found that sheep or deer grazing with the other species did not differ in time spent on different activities than animals in single-species plots. No interactions between species were observed. Overall both species split their grazing time fairly evenly between grass and heather, but spent significantly more time grazing heather during autumn grazing. Sheep consistently spent more time grazing small patches than did deer, and were seen to preferentially graze small patches in some years, unlike deer. Deer were seen to move and lie down more in *Calluna* whereas sheep preferred paths and to lie in grassland. As dunging occurs following periods of inactivity, sheep preferentially dunged on grassland whereas deer preferentially dunged in *Calluna*. From the 15 minute observations few differences were observed in grazing behaviour between species. There was a trend for both species to move more slowly over grass than heather, and most grazing bouts included a mixture of heather and grass. Deer moved across vegetation boundaries more frequently than sheep in 15 minute observations. It is proposed that the degree of vegetation fragmentation will strongly influence the time spent grazing grass and heather by sheep, but not deer, with sheep grazing more heather where grass patches are small and fragmented. The greater time spent moving through heather may also result in increased physical damage by deer. Overall, sheep appeared to be much more affected by the scale of heather fragmentation and habitat use is more strongly focussed on grass patches and tracks.

9.15 Palmer *et al.* (2003) [2+] found that the greatest contribution to variance in annual heather utilisation occurred at the smallest spatial scale studies, ie the quadrat level, with the main effect being distance from the grass patch edge. There was a sharp decline in utilisation with increased distance from grass in all the land management units. On all units, heather was much shorter within 1-2 m of the grass patch edge than further away. Grass availability did not significantly affect relative heather heights in the edge and distant zones of transects. However, the dominant grass species did affect heather height. *Agrostis-Festuca* patches showed the greatest proportional height difference, with heather height in the edge zone 32% shorter than distant heather, followed by *Nardus* at 26% and then *Molinia* at 11%. This suggests that the heather receives much higher impact when adjacent to preferred grass vegetation.

9.16 Oom *et al.* (2008) [2+] mapped a net change over all plots from shrub to mixed vegetation and to a lesser extent to degraded heather. Small changes in spatial pattern were spread fairly evenly across the mosaic. Larger changes, particularly those from shrub to mixed vegetation, were concentrated in a few areas. There were significant linear relationships between heather defoliation rate and the decrease in shrub vegetation/increase in mixed vegetation associated with adjacent grass patches. However, the relationship between defoliation rate and percentage changes in grass and degraded heather were not significant. The combined increase in grass and mixed vegetation cover at resting sites was equivalent to an increase of 27% by area of the grass patches originally classified as resting sites at the start of the experiment. Spatially aggregated patterns of behaviour (ie resting) clearly played an important role and would have been driven, in part, by the initial spatial patterns of vegetation in the different plots.

9.17 Oom *et al.* (2010) [2+] showed there was a significant overall increase in heather defoliation with increasing stocking rate. Frequency and severity of defoliation was higher for the whole year than for summer only – showing defoliation continued though year. Defoliation was not always negatively correlated with distance from the grass edge, but was dependent on the spatial configuration of the mosaic. It was also higher uphill of grass patch than downhill, although this association was found only in summer and not across a year as a whole. The previously reported decline in heather defoliation with increasing distance from grass was found only at low stocking rates; at moderate densities grazing pressure remained fairly constant across the 5 m zone. The contrast between edge and distant defoliation decreased at higher grazing pressures as impact zones were increasingly likely to overlap. However, because the increase in heather defoliation was buffered by an increase in the area affected, the defoliation impact remained relatively low. This situation may persist over a large range of grazing intensities. It was suggested that increased heterogeneity leads to increased resistance to herbivory, as there is a greater total area of ‘impact zone’.

9.18 Sibbald *et al.* (2008) [2+] observed that sheep spent 69% of their time grazing, and of this 69% was on grass patches. Sheep spent more time than expected on larger patches (highly significant on all plots). When observations of sheep grazing on the most preferred grass patch in each plot were analysed, frequencies with which sheep were seen in groups of 4, 5 or 6 individuals were significantly higher than would be expected simply from the number of times that individual sheep visited those particular patches, suggesting that the animals made positive choices to graze there together. Patch sharing was necessary for groups to maintain their spacing (mean of 4.9 m) while grazing grass.

9.19 Grant (1968) [2-] showed that sheep grazing on burned areas tended to be higher in early years when heather was short, falling over time. This effect varied, depending on factors such as wetness, proximity of better grazing on grass, or surrounding tall heather restricting movement.

9.20 Grant & Hunter (1968) [2+] found that heather regeneration was affected by the year of burning, with the effect apparent three years after the end of the burning cycle. There is little clear effect of grazing regime on botanical composition, although this may be confounded by failure to burn one of the sub-plots in one year, which was then carried over to the next burning. Mean heather height at the end of the experiment was however significantly greater in the seasonal low grazing plots (0.05 LU ha^{-1} yr^{-1}). At low stocking rates, sheep were observed to select young heather in both summer and winter. This only broke down at the highest grazing intensity, where grazing pressure was sufficient to maintain heather in short, dense growth forms. The current season’s growth of terminal shoots was shown to be significantly affected by age and grazing pressure, with greatest growth in more recently burned and heavily grazed plots. This is possibly down to increased temperatures near the ground in shorter vegetation. Nitrogen concentration in shoots followed a similar pattern to growth.

Infrastructure

9.21 Welch *et al.* (2005) [2+] found that altering the grazing patterns of free-ranging sheep through, in this case, the provision of shelter, has resulted in a significant reduction in key moss heath species and increased cover of grass in the 15 m zone adjacent to the fence. Pellet group (dung) density was 4-5 times higher in this zone, with an associated increased grass cover at the expense of *Racomitrium* moss.

Ranging behaviour

9.22 Hunter & Milner (1963) [2+] found that flocks did not range as a single unit. Individual sheep exhibited home range behaviour which related to the home range groups from which they were selected, and sheep from the same home range group utilised different areas or 'patch' of that range. Only members from one of the nine family groups had ranges which were clearly different from each other, with related sheep generally ranging over the same area. Shepherding had little long term effect on sheep behaviour with all individuals returning to their home ranges. Supplementary feeding appeared to have little effect on sheep behaviour, being utilised by sheep in whose home-range it was positioned. There was a seasonal variation in distribution with animals becoming more dispersed during the period May to October. Grazing activity declined with an increase in daylight hours and the sheep were more active in the first half of the year.

9.23 Lawrence & Wood-Gush (1988) [2+] found evidence of a strong ability of the marked and unmarked sheep to discriminate between each other. There was large seasonal variation in the distribution of the marked sheep with the grazing area increasing during the summer period. Home ranges were also significantly smaller in the winter period. During the winter period clusters were strongly segregated between age classes with those with the majority of the ewe lambs and gimmers ranging more extensively. Younger sheep were markedly less consistent in their home range behaviour between seasons. There was a consistency of membership between clusters in the two summer periods, but some sheep were found to move between clusters

9.24 Hetherington (2000) [1+] found that in the experimental areas *Calluna* was grazed more at interfaces between sward communities compared to sampling points in which it was dominant. Grazing of other key species such as *Nardus* and *Vaccinium myrtillus* was also greater at the interface between communities. The presence of feed blocks led to a general increase in grazing of key species, particularly graminoids but the only increase observed was for *Nardus*. The changes in grazing pattern led to an increase in deposition of dung near the feed blocks, which could alter soil nutrient availability and could lead to future increased grazing. The results indicated that feed blocks could be used as a passive method of shepherding and also that short term introduction of feeding blocks in under-grazed areas could result in longer term changes in grazing patterns.

9.25 Williams *et al.* (2011) [2+] Ranges were generally elongated across the south/southeast facing slope. Patchiness was greatest in summer followed by autumn, winter then spring. Individual range sizes were less than 20% of the available area and 51.6% of the available area was unvisited by all 11 tracked ewes (core and substitutes) over the survey periods. The lowest range overlap for individuals occurred between summer and winter ranges – sheep generally used different patches inside and outside the plant growing season, suggesting that different patches are more at risk of grazing-related damage in different seasons. The mean number of livestock per unit area was suggested to be too simplistic a management guideline, and more account needs to be taken of spatial and temporal utilization.

10 Do different types of livestock (species and breed), and combinations of livestock, affect moorland habitats differentially?

Introduction

10.1 There is generally accepted that different livestock species graze in different ways, from experiments on grazing preferences and diet selection (see paragraphs 1.26 – 1.29). Much of this work has been driven by the need to understand how available forage is utilized by livestock, and effects productivity, but also has implications for the impacts that livestock have on this environment. This chapter explores the evidence for differences between types of grazing animals, including breed where information exists, as well as species. Wild herbivores, primarily deer but also rabbits are also considered. However, deer feature much less as grazers in the English uplands than in Scotland, so the body of literature relating to deer from Scottish-based studies is not fully considered here. Deer have a tendency to browse more than sheep, and range more widely, although there is also evidence of inter-specific competition where the two species occur together.

Summary of evidence for the effects of livestock species and breed

10.2 There is weak evidence Albon *et al.* (2007) [2+] that sheep are associated with greater grazing and trampling impacts than other livestock types and wild herbivores, at a landscape scale. There is moderate evidence Albon *et al.* (2007) [2+]; Jewel *et al.* (2005) [2-] that cattle impacts on open moorland tend to be localised, using the higher fertility areas more intensively. There is weak evidence Welch (1984 a,b) [2-]; Welch (1985) [2-]; Critchley *et al.* (2008) [2-] that cattle can cause trampling damage to heather and their dung can kill heather plants. There is weak evidence from the former sources that where cattle have access to improved pasture, species from these pastures can be introduced to moorland in dung.

10.3 There is strong evidence Grant *et al.* (1985b) [2+]; Grant *et al.* (1987) [2+]; Hodgson *et al.* (1991) [2+]; Fraser *et al.* (2009) [2+] of greater fine-scale selectivity in the diets of sheep than cattle, when grazing a range of semi-natural communities. Grant *et al.* (1987) [2+]; Fraser *et al.* (2009) [2+] provide moderate evidence that both species select grass in preference to dwarf shrub in summer. There is moderate evidence that cattle are more reluctant to graze heather than sheep Grant *et al.* (1987) [2+], Fraser *et al.* (2009) [2+], but may remove a greater proportion of the woody growth than sheep when they do Grant *et al.* (1987) [2+].

10.4 There is strong evidence Grant *et al. (*1985b) [2+]; Grant *et al. (*1996b) [2-]; Hodgson *et al.* (1991) [2+]; Common *et al.* (1998) [2+] that cattle graze *Nardus* more readily than sheep, and moderate evidence Grant *et al.* (1996b) [2-]; Common *et al.* (1998) [2+] that this can reduce its cover significantly over 5 years or less. However, at the target inter-tussock height at which *Nardus* was most effectively controlled cattle performance was found to be compromised Common *et al.* (1998) [2+].

10.5 There is moderate evidence Grant *et al.* (1996a) [2+]; Fraser *et al.* (2006, 2009) [2+, 2+] that cattle graze *Molinia* more readily than sheep in summer, and that target utilization levels to reduce its biomass can be more effectively achieved through cattle grazing than sheep grazing Critchley *et al.* (2008) [2-], Fraser *et al.* (2009) [2+].

10.6 There is weak evidence Grant *et al.* (1996b) [2-]; Fisher *et al.* (1994) [2-]; Ferrierra *et al.* (2005)[2-] that goats can be effective in controlling graminoid species less preferred by sheep, but are more likely to browse heather and woody species.

10.7 There is moderate evidence that the diet selected by different breed types of cattle is similar, but that for sheep, breed may influence the diet selected Fraser *et al.* (2009) [2+].

10.8 There is moderate evidence that the sward structure produced by mixed grazing with sheep and cattle in autumn led to increased vole populations Evans *et al.* (2006b) [1+] and weak evidence that it resulted in a higher density of meadow pipit territories Evans *et al.* (2006a) [1+].

10.9 There is moderate evidence of benefits to biodiversity of mixed grazing systems DeGabriel *et al.* (2011) [2+], Evans *et al.* (2006) [1+], but there is little evidence of the medium to long-term effects of single species of grazers other than sheep.

Wild herbivores

10.10 There is moderate evidence Albon *et al.* (2007) [2+]; Hester & Baillie (1998)[2-]; Hester *et al.* (1999)[2-]; Palmer *et al.* (2003) [2+] that deer display a lower degree of aggregation than sheep. There is also moderate evidence Albon *et al.* (2007) [2+]; DeGabriel *et al.* (2011) [2+]; Hester & Baillie (1998) [2-]; Hester *et al.* (1999) [2-]; that deer spend more time grazing on grass patches than heather, but range more readily across heather dominated vegetation than sheep. The same sources provide moderate evidence that heather utilization by deer is greatest around grass patches. There is weak evidence Hester & Baillie (1998)[2-]; Hester *et al.* (1999) [2-] that deer grazing patterns are less affected by heathland fragmentation than are sheep, and they do not show a preference for a particular size of grass patch. There is weak evidence of competition between sheep and deer at the grazing unit scale DeGabriel *et al.* (2011) [2+] with the grazing impact of deer greater with sheep removal.

Analysis and evidence statements

Landscape scale assessments of impacts of different grazers

10.11 Albon *et al.* (2007) [2+] found that the recorded presence of sheep was associated with higher grazing and trampling impacts than other mammalian herbivores assessed. The presence of cattle was next most likely to be associated with increased impacts, but more localised. Sheep impacts displayed less evidence of density dependence than deer, but were generally higher. This may reflect their greater aggregation, more limited ranging, and the effects of stock management practices.

Controlled livestock grazing studies

10.12 Grant *et al.* (1985b) [2+] Sheep differed from cattle in 3 main ways: sheep showed greater variability in diet composition both between and within individual animals; sheep but not cattle were able to increase the proportion of certain components in their diet compared with the proportion in the sward, even when the components grew low in the profile or grew in a fine admixture with other components; sheep but not cattle tended to reduce the proportion of certain tall components in their diets compared with proportions in the sward. At the *Agrostis-Festuca* site, the proportions of both broad- and fine-leaved grass leaf in the diets of sheep and cattle generally suggested neutral selection by both animal species. Sheep avoided grazing grass flower stems and were more efficient in avoiding dead material in the sward. At the *Nardus* grassland site, both sheep and cattle preferentially grazed between-tussock vegetation. *Nardus* was avoided by sheep and, to a lesser extent, cattle. Again sheep avoided grass flower stems to a great degree. At the *Molinia* site, sheep and cattle diets were most similar in June and became progressively less similar with advance in season. Initially the decline in similarity reflected the difference in the proportions of grass flower stems (low in sheep, high in cattle) but later the high proportion of *Juncus* spp. in the diets of cattle was a major factor.

10.13 Grant *et al.* (1987) [2+] found that patterns of diet selection in sheep and cattle were similar when grazing both blanket bog and heather moor, with time of year having a marked effect on selection. This is mainly due to the low preference for heath species and the availability of preferred graminoids. On blanket bog the species selected by sheep tended to have low cover. Cattle were less effective at selection and tended to graze higher proportions of cotton-grass leaves. Heather increased in cattle diets in spring when there was a lot of dead cotton-grass (*Eriophorum* spp.), and in sheep in October when the preferred species had died back. On the heath cattle selected similar species to sheep, but these tended to form patches (*Vaccinium myrtillus* and *Juncus*), with sheep better able to select more scattered palatable grasses. There is evidence that cattle are more reluctant to graze heather than sheep; however they were shown to remove a greater proportion of the woody growth than sheep.

10.14 Hodgson *et al.* (1991) [2+] demonstrated that sheep consistently maintained a higher level of extrusa (sampled dietary intake) digestibility than the cattle, reflecting the generally greater degree of selectivity in their grazing behaviour. The absolute differences were relatively small on all grassy communities, but sheep selected diets of substantially higher digestibility than cattle on the shrub communities. Overall, differences between species in rate of biting and grazing time were relatively small and not significant. The marginally higher biting rate of sheep being counterbalanced by the marginally higher grazing times for cattle, so that daily bites were similar. However, there was a significant species x community interaction in grazing time, values being 20% lower for sheep than for cattle on the *Molinia* community but 15-25% greater on the shrub communities. There was a tendency for cattle to increase their intake of *Nardus* at higher amounts of inter-tussock live biomass than sheep, as sheep often graze more deeply into the sward.

10.15 Grant *et al.* (1996a) [2+] demonstrated that six years of grazing by cattle to remove 33% and 66% of annual growth resulted in reductions in *Molinia* biomass by 46-65% and 86% compared to ungrazed, under the low and high defoliation rates respectively. Floristic diversity increased in grazed plots, primarily through increased cover of other broad-leaved grasses.

10.16 Grant *et al.* (1996b) [2-] found cattle grazed *Nardus* more readily than sheep. Sheep were more likely to graze *Nardus* when their preferred grasses were in short supply. Goats were also shown to graze a greater proportion of *Nardus* than sheep when grazed to similar between-tussock sward heights. Sheep grazed less *Nardus* over time as dead material accumulated. Rate of leaf extension of *Nardus* is about half that of *Agrostis* species, suggesting *Nardus* is not prominent due to competitive vigour, but through avoidance by grazing livestock. In cattle-grazed plots *Nardus* decreased in cover and other grasses either increased or stayed the same. Reduction in tiller base weight and selective uprooting by cattle are likely to have played a part. Levels of utilisation which lead to reduced *Nardus* cover and increased *Agrostis* and *Festuca* can be achieved by cattle and goats.

10.17 Common *et al.* (1998) [2+] showed that five years of cattle and calves grazing resulted in a decline in *Nardus* cover by almost half, and a decrease in tussock size especially with the heavier grazing treatment, based on a target sward height of 4-5 cm. Cows on both treatments ingested a greater proportion of *Nardus* than was present in the sward, and the proportion of live to dead material in diet increased over time as the sward adjusted from previous sheep grazing. The heavy grazing regime was effective in controlling *Nardus*, but not compatible with animal performance. The moderate grazing treatment (6-7 cm) may allow acceptable animal performance, and some control of *Nardus*. An increase in inter-tussock palatable grasses was not observed in this study, which may have been an effect of low soil fertility.

10.18 Jewel *et al.* (2005) [2-] observed that cattle grazing concentrated in the lower, more fertile areas, so that 40% of the area was grazed only lightly and 50% not at all (mainly in the heath and *Nardus*/heath grassland). Grassland in more fertile areas dominated by *Agrostis-Festuca* or bracken were used most intensely (84% by area heavily grazed), with most (71%) of the species-poor *Nardus*/sedge community being lightly grazed and mainly used for resting. There is some evidence of greater movement into less preferred vegetation (heath, *Nardus*/heath) later in the season, but animals tend to remain near stock buildings and water points, even when little herbage remains. Overall, little change has been observed in the extent of communities over 10 years.

10.19 Critchley *et al.* (2008) [2-] showed that in mixed grazing paddocks (sheep with summer cattle) *Molinia* cover declined substantially where it had previously been abundant. *Calluna* also declined slightly with mixed grazing, primarily because of localised trampling. *Molinia* cover increased in the sheep-only paddocks and *Calluna* cover declined slightly despite low grazing indices, although there was a significant increase in frequency in the low sheep treatment. Other changes in plant community composition were minor. It was suggested that cows can be grazed in with sheep to remove *Molinia* biomass without detriment to livestock performance, although the stocking levels used in this study would not be sustainable every year. There was no evidence of a significant move towards wet heath communities after 4 years.

10.20 Fraser *et al.* (2009) [2+] found both cattle and sheep to be selective grazers, consuming grass in preference to dwarf shrub. Even at high (60%) heather cover this species formed a low proportion (<10%) of the diet of both species, with the proportion slightly higher for sheep than cattle. The diet of the two cattle breeds, Welsh black and continental cross showed very little difference between breeds. There was greater within species variation in sheep, and Scottish blackface were seen to increase the proportion of heather in their diet in September at the high cover site, unlike Welsh mountain. It appears that commercial breeds of cattle could deliver desired environmental outcomes. However there was shown to be a greater risk of welfare and productivity issues with using such stock in marginal areas

10.21 Fraser *et al.* (2011) [2+] showed that the number of grazing days required to achieve the target *Molinia* utilisation level varied from 49 to 76, reflecting the variation in growing conditions between seasons. *Molinia* cover and biomass was reduced during the grazing season by cattle grazing. The increase in cover in the sheep grazed plots was half that of the ungrazed plots whilst biomass was also less in the sheep grazed plots than the ungrazed plots. Significant time effects were identified with regards to pre-grazing period cover of *Molina* (increase), broad-leaved grasses (increase), fine-leaved grasses (decrease) and dwarf shrub (decrease) over the study period. There were significant effects over time on post-grazing cover of *Molinia* (increase), *Nardus* (increase) and dwarf shrub (decrease). Treatment type had little effect on sward composition year on year, with only *Molinia* showing a significant change (increase) both before and after grazing. Cattle weights improved across 2002 and 2003, but this performance was not sustained and in 2007 and 2008 the cattle lost weight over the grazing period. The loss of weight was thought to be due to poaching caused by exceptionally wet weather, which contaminated the herbage. Sheep weights were significantly affected by year with changes being consistently positive.

10.22 Evans *et al.* (2006a) [1+] appeared to demonstrate the benefit of low intensity mixed grazing with sheep and cattle to breeding meadow pipit with more territories in this treatment than plots grazed by sheep alone, or ungrazed. This monitoring was extended over a longer time period and this showed the picture changing markedly with the number of breeding territories in treatment (3) declining back down to similar levels to the other plots by the 8th year of cattle grazing. The number of territories has declined on all treatments, so there may be other underlying factors, including off-site effects, which have a greater impact than grazing regime.

10.23 Evans *et al.* (2006b) [1+] found that after 2 years, a significantly higher abundance of voles was found in the extensively grazed mixed treatment [(3) cattle and sheep] than in the extensively grazed treatment that contained only sheep (2), and particularly the intensively grazed treatment (1). Densities were highest in the ungrazed treatment. The results suggest that low intensity and mixed livestock grazing could help manage vole populations in establishing woodland, whilst also improving availability to raptors through increased heterogeneity of vegetation.

Goats

10.24 Fisher *et al.* (1994) [2-] found that heights of bog myrtle, rush species and purple moor-grass were lower throughout most of the observation periods (summer-autumn) in treatments where goats were grazing on their own or mixed with sheep. There was some evidence that sheep graze heather shorter than goats. There was no indication of differences in grazing on deer grass, *Agrostis-Festuca* or mat-grass. This appeared to be interim findings.

10.25 Ferrierra *et al.* (2005)[2-] observed that over two grazing periods as rye-grass availability declined, estimates of the dominant proportions of diet from faecal alkane analysis changed from grasses to heath in sheep, with heaths remaining dominant in goat diets. Sheep appeared to be grass-grazers when availability is high, and browsers when grass became limited. Goats were shown to prefer heath species even when grass availability was high.

Wild herbivores

10.26 Hester & Baillie (1998) [2-]; Hester *et al.* (1999) [2-] identified differences in the effects of fragmentation of heather on foraging patterns of sheep and deer, although both species spend a disproportionate amount of time in grass patches. Deer, unlike sheep, did not display a preference for a particular size of grass patch, but ranged more evenly across the heather-grass mosaic and are much less likely than sheep to be affected by changes in vegetation pattern. Deer moved across vegetation boundaries more frequently than sheep in 15 minute observations. It is proposed that the degree of vegetation fragmentation will strongly influence the time spent grazing grass and heather by sheep, but not deer, with sheep grazing more heather where grass patches are small and fragmented. Deer impacts around large grass patches are likely to be greater than that of sheep. The greater time spent moving through heather may also result in increased physical damage by deer. Overall, sheep appeared to be much more affected by the scale of heather fragmentation and habitat use is more strongly focussed on grass patches and tracks.

10.27 Palmer *et al.* (2003) [2+] found that both sheep and deer preferred to graze on grass patches at the grazing unit scale. The main effect on utilisation at quadrat level was with distance from the grass patch edge. There was a sharp decline in utilisation with increased distance from grass in all the land management units. On all units, heather was much shorter within 1-2 m of the grass patch edge than further away. Grass availability did not significantly affect relative heather heights in zones of increasing distance from the transects. The dominant grass species did however affect heather height. *Agrostis-Festuca* patches showed the greatest proportional height difference at 32%, followed by *Nardus* at 26% and then *Molinia* at 11%. This demonstrates that the impact of grazing on heather is much higher when the heather is adjacent to preferred grass vegetation.

10.28 Welch *et al.* (2006) [2+] showed that in two Cairngorm glens, deer reduction resulted in heather utilization declines of 35% and 48% in the last 5 years of the study, reflecting the reduction in pellet group counts, to 32% and 84% of initial counts respectively. Heather recovery contrasted in the two areas with cover gains in Glen Lui and height increases in Glen Derry whilst cover remained sparse. This probably reflects the main grazer, with rabbits taking shoot tips and encouraging lateral spread from buds, and deer grazing whole shoots and side branches, with trampling adding to pressure. In lightly utilized areas in Derry, the heather grew taller in the absence of rabbits, but remained sparse due to more extensive wet soils.

10.29 DeGabriel *et al.* (2011) [2+] found that mixed grazing by sheep and deer appeared to be beneficial for increasing both alpha (within habitat) and beta (taking account of the range of habitats) diversity and minimizing damage to heather in the uplands. This may be related to the greater ability of sheep to maintain short grass. The absence of sheep was likely to result in expanding deer populations and greater impact on heather. More deer dung was present where sheep were absent from a site and amount of deer dung was positively correlated with length of time since sheep removal at a site scale. At the site scale, heather utilisation was positively correlated with the amount of deer dung, percentage of grass and mean smooth grass height, suggesting grazers are attracted to grass and consequently graze the surrounding heather. Length of time since sheep removal had no effect on grazing impacts at any spatial scale. Heather was taller where sheep were present at the site scale, but grass height was not affected by herbivore presence.

11 What are the effects of absence or removal of grazing on moorland biodiversity and other ecosystem services?

Introduction

11.1 Numerous studies have examined the effects of removal of livestock grazing, usually in small plots. Some studies are long-term, with plots in place for over ten years and up to almost sixty years in some cases. Many controlled grazing studies have included an ungrazed treatment, which has allowed clearer comparisons with specific grazing treatments.

Summary of evidence of the effects of absence or removal of grazing on moorland biodiversity and other ecosystem services?

11.2 There is strong evidence that removal of grazing leads to significant declines in species less preferred by grazing livestock, or grazing avoiders, including *Nardus stricta* and *Juncus squarrosus* Hill *et al.* (1992) [2++]; Adamson & Kahl (2003)[2+]; Welch & Rawes (1964) [2-]

11.3 There is moderate evidence that cessation of sheep grazing can lead to an increase in some preferentially grazed grass species Hill *et al.* (1992) [2++]; Welch & Rawes (1964) [2-], and strong evidence that grazing-intolerant species including *Calluna vulgaris* and other ericoids can increase Rawes & Hobbs (1979) [2+]; Hill *et al.* (1992) [2++]; Adamson & Kahl (2003) [2+]; Rawes (1983) [2-]. There is also strong evidence that *Molinia* can increase on degraded wet heath and acid grasslands following grazing removal Hill *et al.* (1992) [2++]; Adamson & Kahl (2003) [2+], to the detriment of less-competitive inter-tussock species.

11.4 There is moderate evidence that exclusion of even light grazing on blanket bog can lead to an increase in cover of grazing-sensitive species, including *Calluna vulgaris*, *Narthecium ossifragum* and *Rubus chamaemorus* and lichens Rawes & Hobbs (1979) [2+]; Adamson & Kahl (2003) [2+]; Rawes (1983) [2-], although Smith *et al.* (2003) [2+] detected little floristic change over 15 years of sheep exclusion, but this may be because of proximity to more preferred vegetation previously mitigating against grazing impact on the blanket bog.

11.5 There is moderate evidence that long-term grazing exclusion can reduce the diversity and fine-scale heterogeneity of upland grassland and heathland, through the loss of low-growing herbs and lower plants Deléglise *et al.* (2011a) [2+]; Welch & Rawes (1964) [2-]; Fryday (2001) [2-]. Overall there is strong evidence Adamson & Kahl (2003) [2+] Littlewood *et al.* (2006b) [2+]; Deléglise *et al.* (2011a) [2+], Deléglise *et al*. (2011b) [2+]; Rawes (1983) [2-]; Welch & Rawes (1964) [2-]; Fryday (2001) [2-] that the effects of grazing-exclusion on diversity will vary inversely with ecosystem productivity.

11.6 There is strong evidence that successional change of most typical upland vegetation types is slow, as long-term grazing exclusion (>30 years) at a number of sites has not resulted in major successional shifts, for example, to scrub or woodland Adamson & Kahl (2003) [2+]; Fryday (2001) [2-]; and Rawes & Hobbs (1979)[2+]; Hill *et al.* (1992) [2++]; Deléglise *et al.* (2011a) [2+], Deléglise *et al*. (2011b) [2+] for exclusion periods of 13-24 and >20 years, due to lack of seed or regeneration niches. There is strong evidence that the time-scale of change can vary between sites and communities Hill *et al.* (1992) [2++], Adamson & Kahl (2003) [2+]; Welch & Rawes (1964) [2-].

11.7 There is strong evidence that vegetation change associated with grazing removal appears to occur largely through vegetative spread Hill *et al.* (1992) [2++], Deléglise *et al.* (2011b) [2+]; Littlewood *et al.* (2006b) [2+]; Welch & Rawes (1964) [2-]; Rawes (1983) [2-] with regeneration of new species from propagules rare. However, Roberts (2002, 2003, 2010) [3+] provided moderate evidence that severely grazing-suppressed species can respond quickly to grazing removal.

11.8 There is strong evidence that invertebrate populations alter following reductions in sheep grazing Keiller *et al.* (1995) [2+] Littlewood *et al.* (2006a) [2+] Littlewood *et al.* (2008) [1++], with responses varying depending on invertebrate group and site parameters. There is strong evidence that spider abundance increases with grazing exclusion Keiller *et al.* (1995) [2+], and moth species diversity increases Littlewood *et al.* (2006a) [2+] Littlewood *et al.* (2008) [1++].

Analysis and evidence statements

11.9 Rawes (1983) [2-] found that areas of blanket bog at Moor house NNR had undergone major changes in species composition, pattern and structure after 14 years of no sheep grazing. Marked increases in species sensitive to grazing, notably heather, bog asphodel and cloudberry were observed, but also in crowberry, which is affected by trampling. There was some subsequent decline in this later species, possibly as competition from heather increased. Spread was generally vegetative and no new species appeared, but some increased from very low initial levels. Colonisation of bare peat was slow. The author summarizes the changes as a shift from *Eriphoretum* to *Calluneto-Eriophoretum*. This study was pre NVC but in essence it describes recovery of a M20 type blanket bog to M19 type.

11.10 Rawes & Hobbs (1979) [2+] found that following exclusion of sheep there was a marked change to the vegetation of *Eriophorum vaginatum* dominated blanket bog in the North Pennines. There were increases in *Calluna* at both the 7 year and 18 year timeframes and a corresponding decline in *E. vaginatum*. The increase of *Calluna* at 18 years was not significant, but the continued decline of *E. vaginatum* was. Lichen response was also marked with increases in both cover and biomass. The mapping work focussed on the wettest blanket bog. This also showed increases in *Calluna* but it is acknowledged that climatic factors could account for this and there was poor control. It was concluded that it is clear that sheep grazing has a major influence in determining the botanical composition of blanket bogs.

11.11 Welch & Rawes (1964) [2-] Seven years of grazing exclusion on three high level plots in the Northern Pennines has shown that palatable grasses increased in frequency, with reductions in mat grass and heath rush. In the plot that was most calcareous and species-rich low-growing herbs reduced in frequency, particularly on deeper soils where grasses grew taller. In this plot the total number of species fell by one third. Very few new species were recorded at any site. The accumulation of a litter layer may have longer term implications for soil nutrient status and micro-organism activity.

11.12 Hill *et al.* (1992) [2++] found that over the nine sites in Snowdonia, N Wales, where stock was excluded low growing species, including some small sedges and heath rush, showed the largest declines. Palatable grasses, herbs and ericoids showed the greatest increases. *Agrostis/Festuca* grasslands on brown earths changed less than more 'heathy' grasslands on podzolic soils where *Deschampsia fexuosa*, *Molinia* or ericoids became more prominent at the expense of *Nardus*, sheep's fescue and heath rush and other low-growing plants.

11.13 Few new species appeared other than broad buckler-fern on grass litter and rowan along fence lines. Almost all change occurred through clonal spread or growth of individuals. The exclusion of sheep increased vole abundance and when vole numbers peaked it resulted in dead grass and moss, but no bare ground. This vole activity also contributes to variation in vegetation biomass.

11.14 Fryday (2001) [2-] found that removal of grazing increased the cover and biomass of fruticose lichens, although the effect may be less at higher altitude. Grazing appeared to promote lichen diversity on grassland and grass-heath, although again this effect may be less marked on true montane heath where vascular plant growth is less vigorous. Development of a dense vegetation mat was seen to mask the effects of limestone substrates and resulted in the development of a lichen flora similar to acidic conditions.

11.15 Adamson & Kahl (2003) [2+] updated findings from ten long-term grazing exclusion plots (30-46 years), which were re-surveyed to assess change. The rate of change varied between sites but was generally slow. Lower altitude grassland sites generally showed declines in *Nardus*, *Festuca ovina* and dramatic declines in *Juncus squarrosus*. These changes have been accompanied by a noticeable increase in herb species. At high altitude grassland sites (also reported in Welch & Rawes, 1964) *Deschampsia flexuosa* and *Carex bigelowii* increased at the expense of the same dominant graminoids. There were marked changes in high altitude bog vegetation where grazing was excluded, including *Calluna* establishment above the typical upper limit outside the exclosures, and increases in *Empetrum nigrum*, *Rubus chaemaemorus* and *Narthecium ossifragum* (see also Rawes, 1983). Lower altitude bog was in an area of low grazing pressure and high heather cover, where observed response to stock exclusion has been small (Rawes & Hobbs, 1979). Biomass increased at all sites. Moss cover generally declined, but lichens increased which may be down to reduced trampling. The low frequency of *Calluna* on one blanket bog site after 31 years emphasized the slow rate of change and long timescales likely to be required for vegetation to reach a new equilibrium.

11.16 Smith *et al.* (2003) [2+] found that, on the raised mire studied, the species composition in plots ranged from that typical of very wet ombrotrophic mires to that more typical of dry moorland. While many plots remained relatively static over the 14 years, 2 ungrazed plots shifted towards the dry end of the axis. This may have been as a response to years of low summer rainfall. The main conclusion was that, following cessation of grazing, significant vegetation change only occurred in a limited part of the mire edges. It was concluded that the restriction of such changes to the periphery may reflect the distribution of sheep on the mire, with the best most accessible grazing being at the edge. The lack of change following cessation of grazing over the wetter areas suggests that the management of re-wetting mires by blocking ditches may have a role in reducing grazing impacts.

11.17 Roberts (2002, 2003, 2010) [3+] reported that a year of no grazing over an extensive upland area allowed greatly increased phenological expression of the full range of species present, resulting in records for a species previously unknown in England (sheathed sedge) and new sites identified for a wide range of species of varying rarity, including alpine foxtail. Profuse flowering was observed in many other species which rarely or sparsely flower under typical grazing. Increased flowering allowed subtle variations in composition of relatively low diversity moorland habitats to be observed. Re-introduction of grazing in the following year saw reduced flowering of species such as marsh foxtail, in terms of frequency and size of flowering stems, and length of flowering period, compared to the ungrazed season. It is noted though in Roberts (2010) that some grazing is required to maintain open conditions for poor competitors, as noted with marsh saxifrage where grazing has been excluded for 10 years.

11.18 Littlewood *et al.* (2006b) [2+] found that underlying soil conditions strongly influenced variation in vegetation assemblage. Vegetation change may itself influence soil nutrient concentrations. Four of the five most successfully restored sites were those managed by grazing exclusion. Mechanically restored samples contained a relatively low cover of bryophyte and had a generally impoverished flora. Management by grazing exclusion alone often produced only a patchy regrowth of *Calluna*, or in some cases, virtually no *Calluna* over the time scale of the projects studied here. Most complete rehabilitation was achieved with cessation of grazing, especially where *Nardus* dominated; *Molinia* can dominate in the absence of grazing and may benefit from summer grazing. The authors conclude that where *Calluna* is absent and with no viable seed bank, or where elevated nutrient levels give graminoids an advantage, herbicide and reseeding may be necessary

11.19 Deléglise *et al.* (2011a) [2+] found that species richness differed between grazed and ungrazed plots at grain sizes of 25 cm x 2 5cm and above, but effect differed between communities. In heath and mesic grassland, evenness and species-richness was higher in the grazed plots, and in xeric calcareous grassland in the ungrazed plots. The variability of species composition between quadrats showed significant differences between grazed and ungrazed plots at all grain sized other than the smallest (5 cm x 5 cm) as dissimilarities in species composition was greater with grazing exclusion compared to grazing in all the three communities. This reflects the finer scale of heterogeneity maintained through grazing, but a greater chance of sampling the same species in different quadrats at larger scales. Leaf trait results show grazing exclusion resulted in a coarse grain of leaf trait heterogeneity, which may reflect spatial aggregation of species with similar trait values. The weaker sensitivity of trait values may indicate a degree of functional redundancy (different species with similar trait values).

11.20 Deléglise *et al.* (2011b) [2+] showed that grazing exclusion decreased graminoid abundance across all communities, and increased legumes in xeric grasslands. Patchiness of grasses did not differ between grazed and ungrazed plots. Long-term grazing exclusion only affected patch size of species rather than other measures of spatial dependence, and effects were significant only in the xeric (low productivity) community, in which patch size increased. Changes in spatial patterns of species did not support changes in spatial patterns of trait values at the scale investigated. The abundance and patch size of some life forms, for example, rosette and non-rosette forming forbs showed a significant response to grazing exclusion, but this did not result in a change in spatial pattern.

Invertebrates

11.21 Keiller *et al.* (1995) [2+] suggested that a reduction in sheep grazing had little effect on species-richness of carabids and spiders, although species composition changed, in favour of those typical of heather dominated, shaded and densely vegetated habitats. Spider abundance was generally higher in the ungrazed treatments. Calculations of diversity, which takes account of both measures, suggested that it increased for spiders on podzolic soils with removal of grazing, but for carabid was highest on the grazed treatment. The opposite was true on the brown earth site. Removal of grazing appeared to increase the diversity of both groups in mid-Wales. Differences were less marked at his site, where the ungrazed plot had been in place for a much shorter time than in Snowdonia. Beetles of the family *Scarabaeidae* (dung feeders) were seen to decrease with sheep reductions. Although less clear, the tendency for *Diptera* was to increase in abundance and biomass with grazing removal.

11.22 Littlewood *et al.* (2006a) [2+] found that heather cover at the quadrat scale (2 m x 2 m) was the variable that explained most *Hemiptera* assemblage variation. *Lepidoptera* restoration success was generally greatest with grazing exclusion, with four of the five highest ranked sites for restoration success of this group managed this way. Sample compositions were also affected by geographic location, but no plant variables were significant in explaining variation in *lepidopteran* assemblages. Grazing exclusion tended to result in patchier re-growth of heather than sites that were mechanically disturbed and reseeded, with *Hemiptera* restoration more successful in the latter sites.

11.23 Littlewood *et al.* (2008) [1++] Overall, the trend was for higher moth species richness in the light sheep grazed and ungrazed plots. There were significantly more species that overwinter as larva or pupae in the ungrazed treatment, and more egg stage in light sheep-grazed. Graminoid feeders were disproportionately well represented in the ungrazed plots, which were characterised by dense grass tussocks. Whilst BAP species were distributed through all treatments, there was a greater than expected proportion in the heavy sheep-grazed plots.

12 Conclusions

12.1 For the purposes of this topic review evidence sources were identified against a number of sub-topics, and summaries of evidence developed for each one. Many of the sub-topics are closely related, and studies often provide evidence against more than one sub-topic. This section attempts to draw out key points and themes that have emerged, which may draw on evidence identified under one or more sub-topics. For each point identified, the relevant evidence statements from Chapters 4 - 11 are presented, with the strength of evidence (**S** – strong; **M** – moderate; **W** – weak) from the reported studies. It must be emphasised that one cannot infer anything from a statement beyond what is stated, for example, if it were stated that there is strong evidence that sheep grazing has a particular negative effect, this does not imply that cattle or other livestock types are better, unless evidence is presented.

12.2 **There is an association between sheep stocking rates at the landscape scale, and the extent and condition of dwarf-shrub communities:**

- There is evidence of a negative association between sheep stocking rates at the landscape scale, and the condition of heathland and blanket bog. **M**
- Sheep have been associated with higher grazing and trampling impacts at the landscape scale than other livestock types and wild herbivores. Cattle were next most likely to be associated with high impacts, but the effects were much more localised. **W**

12.3 **Expansion of dwarf shrub habitat can be slow or lacking under ESA stocking rates:**

- There may be no significant expansion of heathland vegetation under ESA-type stocking rates over periods of up to 10-15 years, particularly where graminoids such as *Molinia* respond positively to reduced grazing pressure. **M**
- Reduced grazing to agri-environment rates, and including cattle grazing, may not result in expansion of heathland. **W**

12.4 **Where heather is present its condition, in terms of structure and canopy cover/frequency, can improve through reduced grazing pressure:**

- A utilisation level of 20% provides a widely applicable utilisation threshold for maintaining heather cover. **S**
- In most cases, annual average sheep stocking rates of less than 1 ewe ha^{-1} yr^{-1} are likely to improve heather condition in mosaics of heather and grasses. **S**
- Grazing intolerant species including *Calluna vulgaris* and other ericoids can increase with grazing removal. **S**
- Setting stocking rate limits that take account of proportion of different vegetation types in a grazing unit can reduce the impacts on dwarf shrub. **M**
- ESA stocking rates can significantly improve the condition of *Calluna* in dry heath over a 15 year period. **W**
- A grazing index (a less precise measure than utilisation) of up to 40% may sustain old heather, and represents the upper threshold above which young heather growth is suppressed. **W**
- There is an interaction between grazing pressure and heather age, with the effect of heavy grazing more marked in older heather. **W**

12.5 **The effects of stocking rates based on estimates of vegetation productivity will vary between sites and years:**

- Measuring the utilisation (ie the proportion of biomass removed by grazing) of key sward components, and particularly those most closely linked to management objectives, gives a better basis for setting grazing management than stock numbers. **S**
- *Molinia* utilization rates of 33% of summer leaf production has been shown to reduce biomass, but cover has been reported as continuing to increase when summer grazing is set to 50% utilisation. **M**
- Productivity of *Agrostis-Festuca* grassland, preferred by grazing livestock, can vary markedly, and consistently, between sites of different soil fertility. **M**
- The annual biomass production of different heather growth phases, and of *Nardus* grassland, is affected by weather conditions, and therefore varies geographically. **W**
- The annual biomass production of *Molinia* varies significantly between years. **W**

12.6 **Relatively light grazing by sheep can affect the vegetation composition and condition of blanket bog:**

- Exclusion of even light sheep grazing on blanket bog can lead to an increase in cover of grazing-sensitive species, including *Calluna vulgaris*, *Narthecium ossifragum* and *Rubus chamaemorus*. **M**
- Relatively light sheep grazing can reduce heather cover on blanket bog. **M**
- Grazing removal or reduction from even very low levels benefits lichen abundance and biomass. **M**
- However, the proximity to more preferred grass-dominated vegetation can result in very low grazing on blanket bog, with no significant floristic change detected over 15 years of subsequent stock exclusion. **W**

12.7 **The overall impact of a given stocking rate is influenced by the size and distribution of patches of preferred grazing:**

- The spatial impacts of grazing on heather are influenced by the size and distribution of grass patches, with greatest impact in the heather zone closest to grass. **S**
- Reductions in the availability of preferred food items can lead to the condition and regeneration of *Calluna* being compromised. **S**
- Change in the utilisation of *Calluna* is not proportional to the change in the numbers of sheep grazing, as sheep preferentially select grassland elements. **M**
- The overall extent of detrimental grazing impact on dwarf shrub is a function of the spatial extent and distribution of preferred grasses and the overall stocking rate. **M**
- There is a significant linear relationship between heather defoliation rate and the change from heather-dominated to mixed vegetation associated with adjacent grass patches. **W**
- The impact on adjacent heather is greatest around the most preferred grass types (for example, *Agrostis-Festuca*). **W**
- Patch choice by sheep can be variable. In some situations they are reported as preferring to graze on large grass areas rather than smaller patches, which may reflect their grouping behaviour, but in other studies they were seen to preferentially select smaller patches in some years. **W**
- The degree of vegetation fragmentation will strongly influence the time spent grazing grass and heather by sheep, but not by deer. **W**

12.8 **Grazing livestock do not range evenly over a moorland grazing unit:**

- Localised grazing patterns can be altered by the provision of infrastructure such as shelter or water. **M**

- Hill breeds of sheep display home-range faithfulness, with the effects stronger in older sheep. **M**
- Feed blocks can be used to alter sheep grazing patterns and encourage sheep to graze less preferred species, but it may have greatest influence on sheep of the closest home-range. **M**
- Cattle impacts on open moorland tend to be localised, as they use the higher fertility areas more intensively. **M**
- An individual sheep's ranging behaviour, and therefore diet, is influenced by its mother. W
- There are seasonal differences in vegetation patch selection, and uneven use of the grazing unit overall. **W**
- Home-ranging behaviour of sheep is not substantially affected by shepherding or supplementary feeding. **W**
- Sheep may graze short heather on re-colonising burned areas in preference to taller heather. **W**

12.9 **Grazing pressure and livestock type influences the balance of preferred to less-preferred graminoid species:**

- There is greater fine-scale selectivity in the diets of sheep than cattle, when they graze a range of semi-natural communities. **S**
- Removal of sheep grazing leads to significant declines in grazing-avoiders, including *Nardus stricta* and *Juncus squarrosus* through increased competition from taller species. **S**
- Grazing influences the occurrence of species that are less preferred by livestock and, where these species become dominant, can be detrimental to habitat conservation. **S**
- Heavy sheep grazing facilitates the spread of *Nardus* in low fertility soils. **S**
- Cattle graze *Nardus* more readily than sheep. **S**
- The impact of target levels of *Molinia* utilisation varies depending on species of grazer and site. **S**
- *Molinia* can increase on degraded wet heath and acid grasslands following grazing reduction or removal, to the detriment of less-competitive inter-tussock species. **S**
- Summer cattle grazing can result in a decrease in *Nardus* cover over 5 years or fewer. **M**
- Light to moderate grazing (ESA-level stocking rates) can increase the dominance of *Molinia*. **M**
- Cattle grazing, either alone or in combination with sheep, reduces the cover and biomass of *Molinia* compared with sheep-only grazing. **M**
- Cattle graze *Molinia* more readily than sheep, and target utilisation levels that reduce *Molinia* biomass can be more effectively achieved through cattle grazing than sheep grazing. **M**
- A grazing level which achieves 33% utilisation of the annual leaf growth can reduce *Molinia* cover, and may allow heather regeneration and increased floristic diversity, whereas a higher *Molinia* leaf utilisation rate of 66% may compromise heather regeneration. **M**
- Cessation of sheep grazing can lead to an increase in some preferentially grazed grass species. **M**
- *Molinia* increased under sheep-only grazing when stocked at ESA stocking rates, with utilization rates estimated at around 33%. **W**
- Grazing favours *Nardus* over *Vaccinium myrtillus*, but *Deschampsia flexuosa* is favoured by no grazing. **W**

12.10 **Sheep may provide a degree of *Molinia* control where dead material is reduced through cutting or burning:**

- Sheep can exert some control of *Molinia* in combination with cutting and burning. **M**
- The presence of sheep grazing can have a positive effect on moorland restoration (through controlling grasses), in combination with other treatments. **M**
- The effect of grazing in combination with other restoration treatments may be more positive on *Molinia-Calluna* sites than *Molinia* dominated sites. **W**

12.11 **Grazing selectivity and choice varies between livestock species and there may be greater inter-breed variation in sheep than cattle:**

- Cattle are more reluctant to graze heather than sheep, but may remove a greater proportion of the woody growth than sheep when they do. **M**
- Diets selected by different breed types of cattle are similar, but breed may influence the diets selected by sheep. **M**
- Goats can be effective in controlling graminoid species less preferred by sheep, but are more likely to browse heather and woody species. **W**

12.12 **Livestock influence vegetation change by mechanisms in addition to grazing defoliation:**

- Sheep will tend to rest and dung on grass patches rather than heather. **M**
- On acid grassland cattle trampling can facilitate heather establishment. **M**
- Sheep resting areas influence spatial patterns of vegetation change, causing a greater degree of aggregation of grass expansion than through grazing alone. **W**
- Cattle can cause trampling damage to heather and their dung can kill heather plants. **W**
- Where cattle have access to improved pasture, species from these pastures can be introduced to the moorland in the cattle dung. **W**

12.13 **Summer cattle grazing is almost as effective as grazing exclusion in facilitating heather establishment from seed:**

- Heather can successfully establish with complete grazing exclusion or summer cattle grazing, in the absence of sheep. **M**
- Disturbance, seed introduction and grazing exclusion or low intensity cattle grazing can facilitate heather establishment in acid grassland. **M**

12.14 **Grazing preferences of livestock vary seasonally:**

- Sheep grazing favours *Calluna* over *Vaccinium myrtillus* (ie *Vaccinium* is consumed more readily, favouring the expansion of heather), with the greatest effect in autumn. **M**
- Utilisation of dwarf shrubs by sheep is lower in summer and greater in autumn and winter. **M**
- Both sheep and cattle select grass in preference to dwarf shrubs in summer. **M**

12.15 **Change in vegetation community type and broad character through grazing reduction or removal may take several decades:**

- Successional change of most typical upland vegetation types is often slow. Long-term grazing exclusion (>30 years) at a number of sites has not resulted in major successional shifts, for example, to scrub or woodland. **S**

- Vegetation change associated with grazing removal appears to occur largely through vegetative spread, the regeneration of new species from propagules is rare. The time-scale of change can vary between sites and communities. **S**
- Acid grassland communities can be very stable, and change little under different grazing regimes over periods of several years. **M**

12.16 **Moderate grazing can maintain plant species-diversity:**

- The effects of grazing exclusion on diversity will vary inversely with ecosystem productivity. **S**
- Long-term grazing exclusion can reduce the diversity and fine-scale heterogeneity of upland grassland and heathland, through the loss of low-growing herbs and lower plants. **M**

12.17 **Periods of summer grazing reduction or removal can benefit populations of key plant species:**

- Severely grazing-suppressed species (grasses and herbs) can respond quickly to grazing removal, through increased growth and flowering. **M**
- Removing or reducing summer grazing can benefit the survival of annual plant species, but in the medium-long term can reduce populations through loss of bare ground and increased sward heights. **W**

12.18 **Low productivity or climatically stressed habitats may respond relatively quickly to changes in grazing pressure:**

- High levels of sheep grazing and trampling can reduce the moss component of montane heath to the benefit of graminoids. **M**
- Montane heath can degrade rapidly, over a period of 5 or 6 years, with increased grazing pressure. **M**
- Bryophyte cover can increase in montane heath habitats over a 10 year period, at the expense of bare ground (which can provide regeneration niches) and grasses. **M**
- Stock reductions to annual averages of around 0.5 ewes ha^{-1} yr^{-1} or less have resulted in improvements in low-productivity upland habitats over periods of around 10 years. **M**
- Where key species are still present, some restoration of montane moss-heath can take place over a ten-year period with light grazing. **W**
- Restoration of montane heath communities may not be achievable under severe degradation, where the organic soil layer has been lost. **W**

12.19 **Grazing levels affects the structure of moorland food webs:**

- Grazing removal increases total invertebrate abundance. **S**
- Grazing intensity and seasonality affects invertebrate species assemblages and the functional groups represented. **S**
- Invertebrate populations alter following reductions in sheep grazing, with responses varying depending on invertebrate group and site parameters. **S**
- The abundance of some moorland bird, mammal and invertebrate species and groups can respond quickly (2-5 years) to changes in grazing regime. **S**
- Grazing influences the composition of moorland bird assemblages, through its effect on the structure and composition of moorland vegetation. **S**
- Uniformly tall swards, and particularly where they are ungrazed, may limit the availability of invertebrate prey to birds. **S**

- Moorland abandonment reduces meadow pipit populations, probably through reduced access to prey. **S**
- Spider abundance increases with grazing exclusion, and moth species diversity increases. **S**
- Grazing affects soil microbial communities with reduced biomass in ungrazed situations. **M**
- Diversity of Hemipteran assemblage is strongly influenced by plant species composition. Diversity is generally greater in grass than heath communities, although the heathland specialists are absent. **M**
- Some species and groups including spiders, harvestmen and pseudoscorpions fared better under light sheep grazing than mixed sheep and cattle grazing. **M**
- Some species of beetle, particularly smaller-bodied species, are associated with more heavily grazed grassland. **M**
- Reduction or removal of grazing can increase vole populations. **M**
- Black grouse numbers can respond to reductions in grazing pressure, but the effect may not be sustained. **M**
- Bacteria dominate under heavy grazing. Fungi make up a proportionately greater contribution to the soil microbial communities where there is light or no grazing. **W**
- Microbial biomass and associated nutrient cycling may be optimal under intermediate grazing levels. **W**

12.20 **Low intensity mixed grazing regimes can have biodiversity benefits:**

- Mixed low intensity grazing favours some invertebrate groups and can have a positive effect on overall arthropod biomass. **M**
- The sward structure produced by mixed grazing with sheep and cattle in autumn led to increased vole populations. **M**
- Mixed grazing systems have biodiversity benefits, but there is little evidence of the medium to long-term effects of single species of grazers other than sheep. **M**

12.21 **Atmospheric nitrogen (N) deposition is likely to influence the effects of grazing:**

- Grazing interacts with N deposition to affect vegetation composition. **M**
- N addition increases heather growth in the absence of grazing, but can encourage detrimental grazing where sheep are present. **M**
- N addition promotes grazing in montane heath, through increased grass growth. **W**
- Reduced sheep grazing may increase the sensitivity of mosses, lichens and bilberry to N addition. **W**

12.22 **Red deer have broadly similar grazing preferences to sheep, but are likely to range more evenly across different vegetation types:**

- Deer display a lower degree of aggregation than sheep. **M**
- Deer spend more time grazing on grass patches than heather, but range more readily across heather dominated vegetation than sheep. **M**
- Heather utilization by deer is greatest around grass patches. **M**
- Deer grazing patterns are less affected by heathland fragmentation than are sheep, and they do not show a preference for a particular size of grass patch. **W**
- The grazing impact of deer on heather is likely to be greater around large patches, due to the lower edge-to-area ratio rather than selection of patch size. **W**
- Competition between sheep and deer can occur at the grazing-unit scale with the grazing impact of deer greater after sheep have been removed. **W**

12.23 **There is a link between grazing and soil erosion and loss:**

- There is evidence of a link between sheep grazing and soil erosion through the creation of bare ground. **M**
- Plant re-colonisation of eroded ground can take place grazing pressure is reduced to an overall annual pressure, of around 0.15 LU ha^{-1} yr^{-1} on mineral soil and 0.03 LU ha^{-1} yr^{-1} or less on peat soil. **M**

12.24 **The impact of grazing on carbon sequestration and storage within moorland is variable, as it effects the relative contribution of different mechanisms:**

- The rate of carbon accumulation is not significantly affected by grazing removal, over periods of up to 30 years. **M**
- Grazing removal increases above ground carbon storage in vegetation and the litter layer, especially where there is a resultant increase in dwarf shrub. **M**
- There is evidence of a trend towards greater soil carbon storage along landscape-scale transitions to lightly or infrequently grazed and disturbed habitats. **W**
- There is some evidence of increased CO_2 sinks in grazed plots but higher methane (CH_4) effluxes. **W**
- Water tables are affected by grazing. Evapo-transpiration is lowered as plant biomass is reduced by grazing and this allows the water table to be closer to the surface. If the abundance of peat forming species is not affected by the grazing the higher water table could improve rates of peat formation. **W**

12.25 **Grazing may have little effect on water quality, at least at relatively low stocking rates:**

- At low stocking rates grazing has little impact on soil water quality in peatlands, compared to ungrazed plots. **W**

13 Discussion

Introduction

13.1 Before discussing the overall findings of this topic review, it should be noted that the quality of evidence was variable. Of the 117 conclusions listed above, only 24 are based on strong evidence (21%), with the remaining 56 of medium quality (48%) and 37 of weak quality (32%). There is a paucity of good quality studies on which to base management. Recommendations for future research and evidence gathering are set out at the end of this section. In places the findings and recommendations will concur to a greater or lesser degree with the experience and views of those involved in managing moorland areas. Some of the conclusions reported here are reflected, for example, in a survey of expert opinion reported in Silcock *et al.* (2012), on the importance of different aspects of grazing regimes, and the implications of changes in livestock and grazing. This review presents the strength of evidence that underpins current approaches to grazing management, and identifies where evidence is weak or lacking, and more information is needed in order to develop widely applicable guidance.

Effects of stocking rate

13.2 The current practice within agri-environment schemes in England of setting limits in stocking rates, usually with lower maxima in winter, can have some effect of improving the condition of the heather-dominated communities, for example, as reported here for the Long Mynd in Shropshire. Removal of a smaller proportion of the annual biomass production of the plant allows height to increase and the canopy to develop in area. There is some evidence that low productivity blanket bog and montane habitats have improved in condition where stocking rates have been reduced to annual averages of around 0.05 LU ha^{-1} yr^{-1} or less, often including off-wintering, and similar rates have allowed some recovery of previously suppressed montane plants in some of England's rarest and most fragile upland habitats. In reality, the effective stocking rate for different parts of a grazing unit will vary depending on a number of factors, many of which are discussed later, including the relative attractiveness of different vegetation types to a grazing animal. The grazing levels that allow recovery of sensitive habitats may therefore be lower or higher than the overall rate, as animals spend proportionately more time grazing areas with nutritional or other advantages. Evidence presented here from studies on North Pennine blanket bog suggests that even very light grazing, in farming terms, can reduce the frequency of many desirable blanket bog species.

13.3 The evidence suggests, however, that expansion in the area of dwarf-shrub communities, on reduction of grazing pressure, is usually limited or slow, as grazing pressure may be concentrated on the margins of dwarf shrubs at the interface with acid grassland communities, and opportunities for establishment from seed in closed grassland swards are limited. Where grazing pressure is low overall, competition from tall grasses often restricts the spread of heathland plants.

13.4 Currently within Higher Level Stewardship there is a degree of tailoring of a stocking limit to the grazing unit, by taking account of the relative proportion of different vegetation types with associated maximum rates, based on differences in likely productivity (Appendix 3). The output is an overall indicative maximum stocking rate for the unit, which may be adjusted seasonally or monthly. This is still a relatively crude approach, and does not take account of geographic and climatic variation, the preference of livestock for different vegetation, and other factors that will influence the variation in productivity between sites, such as soils and topography.

13.5 Some of the reported evidence could be seen as contradictory, in that heather cover in controlled grazing experiments (for example, Hulme *et al.* 2002; Pakeman *et al.* 2003) was seen to increase at stocking rates similar to those applied under agri-environment schemes (around 0.1 LU ha^{-1} yr^{-1}), over relatively short timescales. This may in part reflect the scale or context (see below) at which different studies are set. Small plot studies allow a greater degree of control over the grazing pressure in a given area, whilst the larger paddocks of farm-scale studies allow for greater variation in grazing pressure, perhaps with improvements in dwarf shrub condition and cover in part of the unit off-set by relatively high grazing pressure elsewhere. The findings may also reflect the scale at which vegetation measurements is carried out, and the greater likelihood of detecting small changes in intensively monitored small plots.

13.6 The plot-scale controlled grazing studies also show that the level of utilisation and stocking rate that maintains heather cover varies between studies, depending on factors such as the relative proportion of heather-to-grass in plots. Other climatic and environmental factors, including levels of nitrogen deposition, will influence heather growth, and therefore the impacts of a given stocking rate at different sites. There is evidence from studies presented here that the productivity of a particular vegetation type will vary between sites, and between years at the same site (illustrated, for example, by the different numbers of grazing days required to maintain target utilisation rates or sward heights in different years of controlled grazing experiments). This suggests that the impact of a given set stocking rate based on standard figures will differ between sites and years.

13.7 The various experimental and monitoring studies do however point to stocking rates that could form the basis of generic guidance, or provide a check of whether an observed or calculated stocking rate for a site is likely to have positive results. Understanding of the actual response of the range of vegetation types on a grazing unit requires monitoring designed to collect information on the utilisation of key components of the vegetation and the distribution of grazing impacts. This needs to be done in a way that informs the review and adjustment of grazing regimes to ensure site objectives are met (ie adaptive management). Over time this can also help to improve the generic advice and guidance on setting grazing regimes. There is an inherent trade-off here as considerable effort is needed to acquire this monitoring data, but as yet there is no accepted method for scaling up this knowledge to the landscape scale.

Effects of recent changes in livestock numbers on moorland

13.8 Whilst the detrimental effects of increased sheep grazing on moorland over the second half of the 20th century have been well documented (for example, Thompson *et al.* 1995) and some localised evidence is reported here (Anderson & Radford, 1994), there is as yet limited evidence to indicate large-scale changes in moorland vegetation communities arising from recent reductions in grazing. A recent survey of expert opinion as part of a study commissioned by RSPB (Silcock *et al.* 2012) does however provide a view that reduced grazing pressure is contributing to an improvement in condition of upland habitats, and evidence is presented in this review of improvements in habitat condition and positive responses in important plant populations over relatively short timescales. On the other hand, concerns are expressed by the farming community of the effects of under-grazing, with anecdotal evidence, for example, of the spread of bracken. This was not supported by the national Countryside Survey, which was last carried out in 2007 (Countryside Survey, 2009). The survey detected an increase of 15% in the area of dwarf shrub heath between 1998 and 2007. Whilst not statistically- significant, and reflecting some changes in analysis methods, the greatest increase was detected in the upland zone, mainly at the expense of acid grassland. Other than this, the area of mountain, moor and heath habitats showed very little change.

13.9 Within the dwarf shrub heath broad habitat the main change detected in the upland zone was an increase in the ratio of grasses to forbs, following a decrease in this ratio between 1990 and 1998. Species that decreased in frequency tend to be shorter grasses and sedges, with increases in taller grasses and rushes. The dwarf shrub cowberry (*Vaccinium vitis-idaea*) was however among the species with the greatest increase in frequency over this time. There was a significant increase in measures of competitive species in the bog and upland acid grassland broad habitats between 1998 and 2007, and a decrease in stress-tolerators. Overall the cover of bracken and common gorse decreased significantly, and western gorse and hawthorn increased.

13.10 An analysis of Countryside Survey sample squares from within the Moorland Line only (CEH, 2011) showed similar results with no significant change in species frequency, but some changes in overall cover. Again the cover of bracken and gorse was significantly higher in 1998 than in 2007, while many species such as *Vaccinium*, *Molinia*, *Nardus*, hare's-tail cotton-grass (*Eriophorum vaginatum*) and western gorse (*Ulex gallii*) showed significant increases in cover over the same period. Whilst heather-dominated habitats had increased in extent overall, there was some reduction in heather cover within plots and a non-significant reduction in frequency, which may reflect localised losses.

13.11 The results of these analyses suggest that between 1998 and 2007 there was little indication of large-scale changes in the character of moorland that might result from reductions in grazing pressure. However, there is an indication from the Countryside Survey species results that taller, more competitive plants are increasing in frequency, which may be related to grazing reductions, and is consistent with many of the findings from grazing reduction and exclusion studies reviewed here. Grazing suited-species scores (ie the proportion of species tolerant or adapted to grazing (Critchley, 2000)) indicates that between 1998 and 2007 there was a statistically- significant shift away from grazing tolerant species. Future re-surveys will be necessary to confirm these trends, and assess the effects of further changes in grazing regimes since 2007.

Spatial factors

13.12 In reality, as evidenced here, livestock do not range evenly over an area of moorland and the distribution of sheep in particular is likely to be heavily influenced by the location of preferred vegetation. In addition, many hill sheep management systems utilize sheep home-ranging behaviour, in maintaining 'hefts' or distinct flock grazing areas. There is some evidence presented here for home-range faithfulness in Scottish blackface sheep, and of the influence of family groups in maintaining this. However, there may be breed differences in the strength and pattern in home-ranging.

13.13 Management hefts are likely to be influenced to some extent by the location of the farm and moorland access points, rather than solely the distribution of vegetation types, although there will be an interaction due to the grazing preferences displayed by sheep. The hefting system, or home-ranging behaviour, may have a role in spreading grazing around on shared grazings such as common land. There is no scientific evaluation of the role of hefting in distributing grazing pressure, although the issues are reviewed by ADAS (2008). Despite concerns from farmers that stock reductions and the loss of flocks on common land are likely to result in the weakening of hefts and greater sheep dispersal, a degree of home-range faithfulness may result in increased variation in utilisation of vegetation across large grazing units.

13.14 This variability in grazing pressure across a diverse grazing unit is likely to be a barrier to achieving ecosystem service outcomes, and possibly in particular for biodiversity objectives. The grazing patterns that result from sheep ranging behaviour and grazing preferences, management practices and topography are unlikely to match the conservation grazing requirements of different habitats and species. A reduction in sheep numbers, resulting either from agri-environment schemes or changes to farm enterprise structure, will not necessarily deliver these varying grazing requirements fully. A challenge for conservation advisers and land managers is to better match grazing patterns to the requirements of different habitats. There may be opportunities, for example, to modify hefting patterns as grazing systems change to achieve more targeted grazing. The potential conflicts that arise from the proximity of habitats with different grazing requirements within a grazing unit are explored in a recent report to Scottish Natural Heritage (Holland *et al.* 2010). An associated practical guide and management toolbox was produced as part of this work, which could provide useful pointers for the development of guidance for English moorland.

13.15 There is strong evidence that heather utilisation by livestock in general, and sheep in particular, is influenced by the choice of grazing and resting areas within the home range. Impact on heather and other dwarf shrubs is greatest in a narrow zone around grass patches. The size and distribution of grass patches, along with the proportion of preferred grass species in patches, greatly influences the overall impact and affect of grazing. However, the studies also suggest that there is an interaction between the degree of fragmentation of grass patches and overall sheep stocking rate. Many small patches will help to spread the impact of grazing over a wider area, which may help to protect heather moorland at low to moderate stocking rates, but increases the area exposed to damaging grazing at high stocking rates. A similar area of grass in fewer, larger patches will have a lower edge to area ratio, and therefore reduced area of impact. It is clear that knowledge of the spatial distribution of preferred grazing at small and medium scales within a grazing unit is key to understanding the likely impacts of grazing on heather and other vulnerable vegetation communities.

13.16 On many English moorlands there is often a grass-dominated zone on the margins of expanses of dwarf-shrub dominated vegetation, particularly where management of heather for grouse is practiced. Whilst the zone of high heather utilisation may be relatively small in terms of the overall area of heather it is likely to result in contraction of the heather area over time, and at a faster rate when livestock numbers are high. Whilst there was little evidence reviewed here of the role of burning in distributing grazing around a moor, there is evidence that sheep are more likely to graze on young regenerating heather than older heather, which may reduce the concentration of grazing pressure in the grass-to-heather transitions.

13.17 The evidence for sheep to select grass patches of a particular size class is inconsistent. Evidence from one study and suggestions from others are that sheep preferentially graze larger patches, while the evidence from two related studies is that sheep select small patches. A possible explanation for this is given in Oom *et al.* (2010), who suggest it reflects the background and experience of sheep used in the study. Sheep from the same small group with strong social bonds are more likely to graze as a group, whilst those selected at random from a larger flock for the purposes of a grazing experiment may spread out more and select smaller dispersed grass patches for grazing. This highlights a further issue with extrapolating results from small controlled grazing experiments to commercial grazing systems, in that some of the characteristics of the animals used need to be understood. As well as displaying differences in social behaviour, experimental animals are often non-breeding, which affects their grazing intake and selectivity.

The role of cattle

13.18 There is evidence from heather restoration studies that interventions that cause disturbance and create bare ground can aid the establishment of heather. Whilst it is impractical to implement this on a large scale, there may be a role for cattle grazing on moorland in providing localised disturbance, which could aid dwarf-shrub establishment if sheep grazing pressure is low or absent. Cattle have also been shown to graze less selectively than sheep, and may graze grass species such as *Nardus* usually avoided by sheep. In the medium term this might increase the proportion of preferred grasses in the sward and improve the quality of semi-natural grassland for light/moderate sheep and mixed grazing.

13.19 Cattle grazing needs careful management as it can also have detrimental impacts on vegetation through trampling and dunging, including damage to woody stems of heather. Studies presented here suggest that cattle will tend to spend most of their time on more fertile vegetation and around water supplies, and are unlikely to range evenly over a grazing unit. This may serve to reduce grazing on areas that sheep would be more likely to graze, where cattle are the sole grazers, or it may mean that target vegetation is not grazed to the degree that is required. This uneven ranging behaviour of cattle is likely to result in a greater diversity in sward density and structure, and may offer greater potential for improving the abundance and diversity of different taxa. Provision of water and careful supplementary feeding may be tools that can be used to target cattle grazing at particular areas, or avoid others.

13.20 Evidence from some studies reported here, and others in lowland areas, suggests that diets selected by different breed types of cattle are similar, and that breed influence on diet is much less than between breeds of sheep. This may in theory increase the options of farmers in grazing semi-natural areas, utilising more commercially oriented breeds. However, it is likely that the condition and productivity of such animals will be compromised where semi-natural moorland vegetation is a significant part of their diet, and that native hardy breeds are better suited to these environments.

Grazing removal and low intensity regimes

13.21 There is evidence that periods of sheep removal can benefit not only heather establishment and improvement in condition, but can allow some recovery of heavily suppressed species which have few flowering opportunities, even under light sheep grazing. It is likely that prolonged grazing exclusion could be detrimental to plant species diversity in all but the very lowest productivity or most climatically suppressed habitat, as competition increases and gaps for colonisation are lost. Low-growing species were also seen to reduce in frequency in less species-rich acid grasslands. Targeted short or medium-term grazing exclusion is a tool that should be considered in managing rare or restricted habitats and plant populations that occupy small areas, and which may be preferentially grazed even at low stocking rates.

13.22 Similarly, relaxation or removal of grazing has been shown to allow recovery or increases in population of invertebrates and some moorland or upland birds, notably black grouse, but as swards become dense the effects are reversed as mobility and access to prey is compromised. Low intensity mixed grazing regimes utilising both sheep and cattle may provide a degree of structural diversity, at different spatial scales which would seem to benefit some moorland species including meadow pipit, probably through providing balancing prey abundance and accessibility. There is evidence that tall grass that might be considered as a sign of under-grazing can be important for moth diversity, and can increase insect abundance overall. However, studies also show that some moth species of conservation importance are associated with more heavily grazed situations, and skylarks are associated with short vegetation. A number of other moorland bird species are known to favour tussocky vegetation, for example, curlew, or contrasting structure for nesting and foraging at the territory scale, for example, ring ouzel. Voles, which are prey for top predators such as short-eared owl and hen harrier, have been shown to increase under light or no grazing.

13.23 There is some evidence that lightly grazed or ungrazed moorland vegetation is associated with greater soil microbial diversity, but reduced biomass compared to moderately grazed areas. The role of microbial communities is considered later. Lack of grazing has been shown to increase carbon storage in above ground vegetation and the litter layer and root zone, but may reduce the rate of assimilation of carbon dioxide (CO_2) compared to grazed situations.

13.24 As indicated in the section on recent changes on moorland, there was little evidence from grazing exclusion or reduction studies of succession to scrub or woodland habitats, even after several decades of stock exclusion. This is likely to be due to a combination of lack of seed and the thick litter and vegetation mat providing few gaps for regeneration. The location of many grazing exclusion studies on open moorland is likely to limit opportunities for ingress of seeds of woody species. The study of soil erosion and re-colonisation in the Peak District reported here (Evans, 1997, 2005) provides some incidental evidence of regeneration of birch (*Betula* sp.) and rowan (*Sorbus aucuparia*) on previously eroded ground re-colonised by dwarf shrub. This site is closer to existing woodland than most others included in the exclusion studies and this, in combination with reduced competition, is likely to have aided colonisation of tree species over relatively short timescales.

13.25 It would seem that there is a role for targeted grazing exclusion or removal in allowing habitat or population recovery or providing habitat mosaics for different species. For restoration and recovery clear site-specific targets need to be set, that inform criteria for how and when grazing can be re-introduced. This requires better information on timescales and milestones of recovery, which can be gained in part by monitoring studies.

Under-grazing

13.26 The review did not identify any studies that specifically attempted to quantify when moorland might be considered under-grazed. This is not entirely unexpected as the concept of under-grazing is largely a value judgement and dependant on the objectives set for a site or feature. Whilst no studies have provided a definition or criteria that identify under-grazing in a systematic way, there are pointers from a number of studies to various scenarios that might be considered under-grazed, in terms of the objectives set:

- loss of low-growing components of a sward through shading from taller grasses;
- dominance of *Molinia* in terms of height and degree of tussockiness overtopping dwarf shrub and other inter-tussock species;
- reduced prey accessibility to moorland birds, affecting their breeding success;
- significant reduction or loss of regeneration niches for annual plant species; and
- loss of short or varied swards required by a particular target bird or invertebrate species or group.

13.27 Currently under grazing is recorded as a reason for unfavourable condition on less than 0.5% of the area of upland SSSI in England. There is evidence from some studies that habitats on very nutrient poor substrates or that are exposed to climatic stress, such as montane heaths and blanket bog at high altitude, are unlikely to suffer from under-grazing.

13.28 The criticism of allowing or encouraging under-grazing is often levelled by farmers at agri-environment grazing regimes aimed at restoring areas of habitat, by farmers. This is based on a perception that the available grass is not fully utilised by livestock, resulting in tall swards, a reduction in the area over which stock readily graze, and subsequent reductions in fodder quality. Whilst the previous section suggests there are benefits that can be had from removing grazing in some situations, most conservation scenarios require a degree of grazing. This may differ in intensity, timing, duration or frequency to that practiced for purely agricultural outputs. As discussed previously there is a challenge in identifying more spatially explicit objectives within a grazing unit, taking account of biodiversity, farming and other ecosystem service outcomes, and influencing the distribution of grazing to deliver these. Part of this challenge is to develop a common understanding of what constitutes true under-grazing for different outcomes including livestock management, and how this might look in different habitats. Scientific studies, that are more agriculturally focussed than the majority considered here, might provide some insight.

Wild herbivores

13.29 Few studies have included an assessment of the impacts and effects of wild herbivores, although many Scottish-based studies include red deer as they are widespread and of commercial significance in the Scottish Highlands. Red deer occur much more locally in England, but some evidence is included here as it may aid decision making by advisers and land managers where they occur, and they may acquire greater significance as livestock numbers decline further on moorland. Additionally, other species of deer are increasing in numbers mainly in the lowlands, but may become more of an issue in upland habitats. There was evidence from some studies that rabbit grazing can have locally significant effects in limiting habitat recovery through grazing and burrowing activity.

Grazing impacts on soils, water and carbon

13.30 A significant impact caused by grazing on ecosystem services has been the creation of bare ground and the soil erosion that may follow. This affects the moorland resource, its productivity and the potential for habitat restoration. It also results in siltation of watercourses and reservoirs. Further evidence is provided in soil erosion studies reviewed here of the need to limit grazing pressure, and suggests that stocking rates similar to those likely to improve habitat condition can also help the re-colonisation of erosion scars. However since erosion is often initiated on steep ground and where preferred grasses are found, the effective grazing pressure on these areas may be higher than the average for the grazing unit. This again therefore needs monitoring and consideration of the spatial distribution of grazing pressure.

13.31 Studies on the role of grazing in carbon sequestration are few. Whilst evidence was found that grazing reduced carbon storage in above-ground vegetation and the upper soil horizons compared to ungrazed plots in studies covering treatment periods of over thirty years there was no evidence of a consistent effect of grazing on carbon sequestration in deeper soil horizons in moorland peat and organic mineral soils. There was no evidence that grazing affected carbon accumulation in peat, but grazing may positively influence peat forming conditions through promoting a shallower water table. The evidence from these studies comes largely from work at Moor House NNR, where only light summer grazing and grazing exclusion treatments have been compared. The work of Bardgett *et al.* (2001) however suggests that, at the landscape-scale, there may be contrasting levels of soil carbon storage between intensively grazed grassland and more extensively managed grassland habitats. This study hints at the possible broad influence of different management and land use on soil carbon storage, which perhaps has not been apparent from experimental or more geographically limited studies with relatively small grazing treatment differences, or which may not have been in place long enough for soil carbon concentrations to diverge.

13.32 Similarly there is no evidence from studies at Moor House NNR of grazing effects on water quality at this site. The effects of grazing on both carbon sequestration and water quality would benefit from further studies on different soil types and involving different grazing regimes and intensities.

13.33 Grazing does appear to influence soil microbial communities, in term of biomass and the relative contribution of bacteria and fungi, which in turn affects soil processes such as the rate and efficiency of nutrient cycling. Removing grazing results in reduced microbial biomass and nutrient (carbon and nitrogen) cycling, due possibly to reduced dung inputs and changes in the character of plant litter. There is evidence that microbial biomass and associated nutrient cycling may be optimal at moderate grazing levels. There is also evidence of a greater proportion of fungi in the soil biota of less intensively grazed and ungrazed sites. Fungal-dominated soil food webs have been characterised as promoting slow and efficient nutrient cycling (for example, Wardle *et al.* 2004). This in turn may allow slower growing and less competitive plant species to exploit resources over more competitive species (Bardgett *et al.* 2003).

13.34 One study in this review looked at the effect of grazing on drainage and run-off, an important issue affecting water capture and supply and flood management. It did not find any significant grazing effect. However, this and related studies at the same site found a significant effect of grazing on water-table depth in peat soils, which was closer to the surface with grazing. The study hypothesises that reduced water table depth through burning and grazing can lead to quicker ground saturation and increased overland flow. No effect on water table depth was found after eight years of grazing removal on a site with organic mineral soil.

13.35 In summary the evidence above suggests that, whilst the exact range of grazing pressure that maintains the desired composition and structure varies between habitats and sites, generally ‘moderate’ and ‘variable’ (both spatially and temporally) levels of grazing are the most appropriate for delivery of many ecosystem services (including those related to soil carbon and biodiversity), though not necessarily those related to animal production. The challenge is defining ‘moderate’ for a given situation and then monitoring to ensure that the initial prescriptions are appropriate for that situation, or that appropriate modifications can be made to the grazing regime in light of findings and changing conditions.

13.36 Grazing has been a major factor in driving the evolution of England’s uplands and it should be recognised that these are productive landscapes. There must be research undertaken to understand the relationships between all ecosystem services in these systems, with due consideration of their value for production, regulating, supporting and cultural services for locals, visitors and the wider population.

Research recommendations and gaps

- Overall, the evidence we have to allow us to manage the uplands appropriately is incomplete. Given this incompleteness, management should be adaptive, with initial management decisions and agreements, which could include indicative stocking rates, seen as a first approximation. This should be based on the best available information, but then adapted based on subsequent monitoring of the effects and impacts of the management activity, including grazing.
- There is a great need for monitoring to provide better site level information of grazing impacts and achievements – including assessments of the distribution of grazing pressure as well as the response of habitats or species. Methods need to be improved to ensure that ecologically meaningful measurements are made, and it can be done quickly and efficiently.
- Monitoring needs to be designed so it can inform management adjustments at the site level, but also to improve the evidence base for setting grazing regimes. There are now a large number of Higher Level Stewardship agreements in place where grazing levels have been set to deliver environmental outcomes. Many sites have previously been managed through classic agri-environment schemes or other management agreements. Well designed and targeted monitoring of this resource and the development of case-studies, could greatly improve our understanding of grazing-related change, including timescales and trajectories of recovery.
- Grazing management regimes should be based on clear, site-specific objectives. This requires better information on a number of levels; the grazing requirements of habitats and species; where key species or groups are present or are likely to occur; and how priorities are set at the site level. This will inform decisions on the types of grazing required, how best it can be achieved and how to modify decisions in the light of monitoring.
- Grazing management agreements may need to take account of short term objectives, which may require time-limited grazing activity, as well as longer-term outcomes. Short periods of heavy grazing may be specified to control invasive or competitive grasses, or create disturbance to allow establishment of particular species, for example, heather. Rotational grazing with cattle within a grazing unit could be used to create spatial and temporal heterogeneity.
- Trajectories of change in different vegetation types by reduction or removal of grazing need to be better understood, in order to decide when further interventions may be necessary to achieve the desired outcomes, and also what biodiversity or other ecosystem service benefits may occur during successional stages that may be seen as unfavourable or under-grazed in farming terms.
- There is a challenge in developing a common understanding of what constitutes true under-grazing for different outcomes, including livestock management, and how this might look in different habitats.
- A better understanding of the grazing and ranging behaviour of the common hill sheep breeds in England is needed, as the few studies that exist are based on Scottish blackface sheep. Possible changes arising from changes in the stratified sheep industry,

including the trend for cross-breeds in particular, need to be evaluated in terms of what they may mean for grazing levels and patterns on moorland.

- There is a need to explore how information on the spatial distribution of vegetation types in a grazing unit should be used more effectively in setting stocking levels. This could include the examination of the potential role of hefting, as hefting will affect how animals will interact with the pattern of vegetation and its utilisation, and how it could be used as a tool to influence the distribution of grazing in a heterogeneous moorland area.
- There is a need to develop a more meaningful Livestock Unit (LU) system which takes into account not only the animals' nutritional requirements, but the grazing choices that are made by different species, breed types and classes of stock when fulfilling these.
- Further research is required into techniques that can be used to influence the spatial distribution and feeding choices of sheep and cattle, including the provision of water and the use of supplementary feeding. Cutting or burning areas of less preferred vegetation and standing dead material can improve the attractiveness of underutilised areas, and the role of these techniques could be explored further.
- The interaction of grazing and heather beetle damage should be evaluated. This review revealed no worthwhile information on any kind on the impact of heather beetle and what influences subsequent heather recovery.
- More evidence is needed on carbon budgets in different grazing/soil combinations. As management moves towards considering ecological services in the round, then understanding the trade-offs between different services, such as carbon sequestration and livestock production, will be necessary to judge what future management is most suitable.
- More evidence is needed on the impact of grazing on water quality in different soil. Most of the studies in this area have been done at Moor House NNR where background grazing levels are light (around 0.02 LU ha^{-1} yr^{-1}). Comparisons with more typical agricultural grazing levels would provide a greater understanding of the effects of stock reductions on water quality and other ecosystem services.

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16 Glossary

This glossary is set out to provide definition to terminology used in this report.

Term	
Agrostis	*Agrostis capillaris*, common bent. A grass.
Auchenorrhyncha	This sub-order of the Hemiptera includes cicadas, leafhoppers, treehoppers, planthoppers, and froghoppers.
Biomass	The total mass of living things in a particular area.
Brown earth	A freely draining soil-profile type with only slight horizons. It has a mull humus in the surface horizon and very little differentiation of horizons below. Brown earths are well-weathered and slightly leached soils.
Bulk density	Also known as dry bulk density. The mass of dry material, per unit volume.
Calluna	*Calluna vulgaris*, ling, heather. A woody ericoid species.
Carabid	A beetle of a family (*Carabidae*)
CH_4	Methane
CO_2	Carbon dioxide
Common Agricultural Policy	A European Union mechanism by which agricultural producers receive support payments, to aid access to markets and environmental protection.
Exclosure	An area from which unwanted animals are excluded.
Floristic/Botanical diversity	Includes both species evenness (relative abundance) and species richness (number of species/unit area).
Graminoid	Monocotyledonous, usually herbaceous plants with narrow leaves growing from the base, usually taken as grasses, sedges and rushes.
Heft, Heaf	The acclimatising of a flock of hill sheep to 'their' part of the hillside.
Hempitera	A large order of insects that comprises the true bugs, which include aphids.
Herbivory	The eating of plants, especially ones that are still living.
Higher Level Stewardship	One element of the Environmental Stewardship (ES) scheme - a government scheme that is open to all farmers, land managers and tenants in England. It is a voluntary scheme, designed to deliver significant environmental benefits in high priority areas.
Lepidoptera	An order of insects that comprises the butterflies and moths.
Less Favoured Area	A term used to describe an area with natural handicaps (lack of water, climate, short crop season and tendencies of depopulation), or that is mountainous or hilly, as defined by its altitude and slope.
Molinia	*Molinia caerulea* (L.) Moench.

Table continued…

Term	
Moorland	A term use to describe unenclosed upland areas dominated by a range of semi-natural vegetation types. Not synonymous with peatlands.
Moorland Line	The Moorland Line encloses land within England which has been defined as predominantly semi-natural upland vegetation, or predominantly of rock outcrops and semi-natural vegetation, used primarily for rough grazing.
Nardus	*Nardus strictus* (L)
National Vegetation Classification (NVC)	A phytosociological classification describing the plant communities of the British Isles.
Paddock	A small field or enclosure.
pH	A measure of the acidity or alkalinity of a solution or material.
Plot	A small piece of ground marked out for experimental purposes.
Podzol	An infertile acidic soil having an ash-like subsurface layer (from which minerals have been leached) and a lower dark stratum.
Quadrat	Each of a number of small areas of habitat selected at random to act as samples for assessing the local distribution of plants or animals.
Racomitrium	A genus of moss species.
Species Richness	Total number of non-native and native taxa per plot (excluding lichens, mosses and liverworts but counting species recorded to genus only or amalgamations of two taxonomically difficult species). This is a simple measure of plant diversity. Increases in plant diversity may not always be beneficial for habitats.
Treatment	The use of a chemical, physical, or biological agent to preserve or give particular properties to something, often used to describe the varying conditions operating in an experiment.
Water table	The distance of a waterlogged zone beneath the surface. Note that in many bogs this water table is not the ground water, in that it is discontinuous with a more freely drained zoned at its base. However, in raised bogs, water table in bogs may be continuous with ground water, but largely not interacting, because the water table is raised bog the gravitational level of the ground water due to low hydrological conductivity of peat.

Appendix 1 Findings from AE monitoring of classic scheme moorland option and tiers

Moorland vegetation was monitored in six upland ESAs between 1989 and 1998, with additional survey on Dartmoor in 2003 and 2010. Grazing pressure was expressed in terms of Biomass Utilisation (BU), the proportion of annual shoot growth removed by grazing. In all ESAs, grazing pressure was moderate, typically in the range of 10-25% BU, with no significant difference in BU between Tier 1 and non-agreement land after 10 years. Findings from monitoring of ESA scheme with heather moorland objectives are summarised below.

Lake District ESA

Ten fells were surveyed in 1993 and 1996, five non- agreement, four in Tier 1 and one in Tier 2. Heather biomass utilisation was consistently higher across all tiers in 1996, and the much lower levels recorded in 1993 are probably attributable to methodological factors (ADAS, 1997a). It was apparent however that there was no difference in the change in BU on fells under different agreement tiers, or non-agreement fells. No relationship between stocking rates and BU was detected, or between reduction in stocking rates and change in BU. Significant differences between fells were detected however, and the two highest values for both BU and proportion of quadrats with suppressed heather were recorded on non-agreement land, and the lowest on agreement land under the tier 2 option.

Differences in mean winter stocking density was significant between tiers, ranging from 0.07 LU ha^{-1} in tier 2 to 0.41 LU ha^{-1} in non-agreement.

North Peak ESA

A reduction in heather grazing pressure between 1993 and 1996 was detected across all grazing units with a fall in mean BU from 17% to 9.3% (ADAS 1997b). There was no significant difference in grazing impacts between tiers, and all units were subject to similar patterns of change in BU between years. Across all grazing units a significant positive relationship was found between mean grazing levels (BU) and mean annual stocking densities. The strongest correlation was with mean stocking densities in September and October, indicating that grazing in this period contributes significantly to annual grazing pressure on heather.

Whilst there was no change in already moderately low stocking levels on tier 1 land, of 0.15 LU ha^{-1} with additional off-wintering, over the period, tier 2 land saw a reduction with extended off-wintering, beginning in October.

There was no evidence of change in spatial distribution of grazing over time, resulting in continuation of clusters of heavy grazing, despite attempts to reduce these through shepherding and burning plans. As with findings from Dartmoor, high levels of grazing tended to be associated with short heather at low cover, close to palatable grasses.

Sheep distribution was also monitored in the field, which showed that the highest mean densities of sheep were found on grassland or mosaics of grassland and heath. This is partly dependant on the relative proportions of different vegetation types, with greatest concentrations on these grassland or mosaic areas where they occupy a small proportion of the grazing unit. As a rule however, stocking rates on sub-dominant heather were over three times higher than on dominant heather. Concentrations on grassland and mosaics were greatest in autumn before the lambs were removed.

South West Peak ESA

Six heather grazing units were surveyed in 1993 and 1996, the first survey prior to ESA launch. Between surveys mean BU fell from 20% to 11%, and the proportion of quadrats suppressed fell from 61% to 40% (ADAS 1997c). Decline in BU was consistent across Tier 1 and Tier 2 sites, and significant in all but one grazing unit.

No significant relationship was detected between BU and grazing levels in the year preceding heather survey. The proportion of heather-to-grass vegetation in a grazing unit seems to be of greater importance, with grazing concentrated on the grass area, resulting in relatively low BU on small areas of dense heather. Highest BU levels were found where heather was least dominant and in close proximity to bilberry and grasses. However, the grazing unit with the lowest BU also had the lowest stocking rate.

Shropshire Hills ESA

A baseline survey from the first winter of ESA operation is reported. Results indicated that heather BU varied significantly between grazing units, but not between tiers (ADAS 1998a). The proportion of suppressed quadrats also varied significantly between grazing units, with 61% of quadrats suppressed overall. On some units high levels of suppression arose from the high proportion of old heather which is less tolerant of heavy grazing. The relationship of decreasing BU with increased heather height and cover was observed in here, as in other ESAs.

Data for stocking rates were not available, but it was noted that the unit with the lowest BU was not grazed in 1994-1995.

Dartmoor ESA

Monitoring on Dartmoor adopted a whole moorland approach across a range of vegetation types, rather than sampling only heather-dominated grazing units. Over the period 1994-1997 BU increased on non-agreement land, resulting in suppression and loss of heather (ADAS 1998b). Species tolerant of grazing increased in frequency. Whilst stocking level information is not available, the incidence of animal droppings increased between these two survey years. The evidence suggests that the stocking rate was above the 0.29 LU ha^{-1} estimated for Exmoor at the time, which is also the same as the mean stocking rate for a sample of dwarf-shrub dominated grazing units in SW England that were considered to be in good condition (Smallshire *et al.* 1996). A high incidence of pulled heather stems was probably related to cattle grazing.

Land in the more restrictive Tier 2 had lower levels of BU in 1997 than non-agreement and Tier 1 land, and in general agreement land had lower levels of BU than non-agreement. Vegetation height was also greater on agreement land which may indicate lower grazing pressure under the scheme. The prescribed stocking rates for Dartmoor ESA are 0.225 LU^{-1} (0.17 LU ha^{-1} winter) on Tier 1 land and 0.17 LU ha^{-1} (0.08 LU ha^{-1} winter) on Tier 2.

Results of this and other work on Dartmoor on heather-dominated moorland suggest that only dwarf-shrub heath in good condition can withstand moderate grazing levels around those prescribed for tier 1. Levels of BU were particularly high on fragmented heather within acid grassland, where heather suppression and loss was likely to continue.

Repeat monitoring on Dartmoor Forest in 2010, and comparison with previous surveys (Poulton 2010) suggest that heather cover and condition continued to deteriorate after nine years of ESA management. Grazing indices were again generally greatest where heather is fragmented within acid grassland, in line with earlier monitoring findings.

Exmoor ESA

A Tier 1 option specified relatively low stocking rates aimed at maintaining existing dwarf shrub heath. Applications for Tier 2 were accepted only for units where heather was in poor or suppressed condition, or where there was high cover of western gorse.

Across the grazing units in the survey, moderate levels of biomass utilisation and suppression were recorded in both years, with little difference between the years (ADAS 1997d). The mean stocking rate of 0.29 LU ha^{-1} recorded in 1996 still seemed to result in poor heather cover and condition. There was only weak evidence of a relationship between stocking rate and BU, with some evidence of clustering of high levels of grazing pressure.

One previously heavily grazed site entered in tier 2, in which annual stocking rates had reduced markedly from 0.42 LU ha^{-1} to <0.05 LU ha^{-1}, displayed a large reduction in BU from over 70% to 10%, with a corresponding decrease in suppression. On grass moorland sites monitored separately, a significant increase in frequency of heather and change from an acid grassland to heathland NVC type was seen in one stand on a grazing unit where annual stocking rate had been reduced to 0.2 LU ha^{-1}. This suggested recovery of dwarf shrub is possible in some situations.

The results tend to confirm findings from other studies, for example, Bardgett & Marsden (1992), which suggest that mean annual stocking rates greater than 0.225 LU ha^{-1} (1.5 ewes per hectare, based on EU Livestock Unit conversion rates) are likely to result in declines of heather cover and condition.

Table A Summary of ESA stocking rate prescriptions, and outline monitoring findings

ESA	Prescription maximum stocking rates	Monitoring results	1996 BU
Lake District	Fell without heather 0.3 LU ha^{-1}; tier 1 heather fell summer 0.225 LU ha^{-1}; winter 0.169 LU ha^{-1}; tier 2B summer 0.15 LU ha^{-1}; winter 0.1125 LU ha^{-1}; tier 2C summer 0.1 LU ha^{-1}; winter 0.075 LU ha^{-1}.	No tier effect detected, but the lowest levels of Biomass Utilisation and Suppression on tier 2 site. Low BU at each site in first survey probably down to systematic error. Over 50% suppression in 1996.	16.9
North Peak	T1 summer 0.15 LU ha^{-1}; winter 0.1125 LU ha^{-1}; T2 summer 0.1LU ha^{-1}; winter 0.075 LU ha^{-1}.	Mean BU reduced from 17% to 9.3%; quadrats suppressed from 75.3% to 32.8%.	9.3
South West Peak	Tier 1 summer 0.225 LU ha^{-1}; winter 0.169 LU ha^{-1}; tier 2C summer 0.1 LU ha^{-1}; all livestock removed winter.	Mean BU fell from 20% to 11%; no evidence of a tier effect. 40% suppression in 1996.	11
Shropshire Hills	Tier 1 summer 0.225 LU ha^{-1}; winter 0.169 LU ha^{-1}; supplementary winter reduction to 0.112 LU ha^{-1}; tier 2 summer 0.1 L Uha^{-1}; all livestock removed winter.	First year results only, mean BU 14%; 61% suppression.	14
Dartmoor	Tier 1 summer 0.36 LU ha^{-1} grassland, 0.225 LU ha^{-1} other moorland; winter 0.235 LU ha^{-1} grassland, 0.17 LU ha^{-1} other moorland (maximum 0.04 LU ha^{-1} ponies in addition). Supplement for winter cattle removal; tier 2 summer 0.17 LU ha^{-1}, winter 0.08 LU ha^{-1}, winter livestock removal supplement.	Mean BU in 1994 was 32%, in 1997 this was 41.5% on tier 1 land and 27.4% on tier 2. Highest BU in acid grassland at 53.8%. Overall 88% quadrats suppressed in 1997.	32
Exmoor	No specific stocking rate tier 1 part 4, avoid concentrations on sensitive areas. Tier 1 part 5 summer 0.225 LU ha^{-1}; winter 0.15 LU ha^{-1} and no cattle; Tier 2 summer 0.1 LU ha^{-1} all livestock removed winter.	Little change between years; no clear trend in tier 1, significant reduction in tier 2; some evidence of dwarf shrub recovery on grassland.	18.5

Appendix 2 Comparison of stocking rates applied to moorland habitats under HLS maintenance and restoration regimes, and environmental cross-compliance restrictions

Table B Summary of ESA stocking rate prescriptions, and outline monitoring findings

Moorland habitat feature	Indicative maximum annual stocking rate (LU ha^{-1})		
	Environmental cross compliance	**HLS maintenance**	**HLS restoration**
Montane heath	0.05	0.017	0.008
Blanket bog	0.07	0.035	0.018
Flush, fen and swamp	0.07	0.035	0.018
Wet heath	0.09	0.044	0.022
Dry heath	0.2	0.101	0.051
Western heath	0.09	0.044	0.022
Calcareous grassland	0.2	0.101	0.051
Fragmented heath	0.2	0.101	0.051
Improved grassland	1.3	0.674	0.4
Grass moorland		0.15	0.075
Dense bracken		0	_
Non-grazeable (scrub, rock, scree)		0	_

Appendix 3 Calculation of livestock units (LUs) – draft Natural England Technical Information Note

Introduction

This Technical Information Note describes livestock unit equivalents for domestic grazing livestock. It is designed primarily to provide accurate information to set appropriate stocking rates for the restoration and maintenance of natural and semi-natural vegetation for the species and breed of livestock grazing the habitat. It may also be used to set stocking rates to restore or maintain other vegetation types.

Livestock units

The use of livestock units (LU) to describe grazing livestock came about some years ago to help determine overall grazing pressure on farms. Originally they were intended for ruminants only, but their application has been extended to include horses, pigs, and even poultry.

The existing way of describing types of livestock in terms of LU as defined by the European Commission (EC) can be seen at Table C. Although they are the officially accepted LUs, they are generalised and take no account of the different sizes of individual breeds. To comply with EC regulations the figures in Table C should be used when setting Article 13 requirements, but this is not consistent across agri-environment schemes and can result in confusion, or unsuitable stocking rates.

Different breeds of animals of the same species have different mature liveweights, which, in turn will affect the amount of forage they require.

Feed intake (or appetite) plays a key part in the calculation of LU, and is also crucial when considering suitable grazing management on any piece of ground.

Table C European Commission LU equivalents

Livestock	Livestock equivalents
Cattle over 2 years of age	1.0
Cattle 6 months - 2 years	0.6
Sheep	0.15
Equines	1.0

As a result, a more systematic way of calculating LUs has been produced, which takes into consideration those LUs used in the classic agri-environment schemes and by the EC. It is based on available research data on grazing animal food intake and performance, although it is acknowledged that this is poor in places.

Revised LU figures for livestock, as detailed in this Information, have been used in the Average Stocking Rate Calculator in the Technical pages on the RDS intranet, to enable an accurate annual average stocking rate to be determined for grazing units.

Domestic livestock

Table D classifies the three main types of domestic livestock into small, medium or large, dependent on the average mature live weight that might be expected for any particular breed.

Table D Animal weight categories

Animal	Liveweight (kg)		
	Small	Medium	Large
Ovine – Sheep	< 50	50 - 70	>70
Bovine – Cattle	<500	500-700	>700
Equine – Horses	<300	300-600	>600

Table E gives LU values for the different categories of domestic livestock in Table D. The baseline for Table E is a 650 kg cow - equivalent to 1 LU. Values for other livestock have been calculated to be consistent with this baseline value (for example, a 65 kg sheep will be equivalent to a tenth of a 650 kg cow, therefore, 0.1 LU).

The calculation for equines is slightly different, because they are not ruminants and their digestive system is less efficient in converting food to energy.

Table F (below) details the liveweight categories for most common breeds of sheep and cattle used in this country.

It is generally accepted that cross bred animals have mature liveweights which are the average of those of the parents (some common crossbreds are included in the lists already). Inevitably there are breeds which are not mentioned, and some animals will be smaller or larger than the norm. The lists should be used as a guide, and not as a regulation.

Table E Livestock unit values for grazing livestock of different weights.

Animal	Livestock unit		
	Small	Medium	Large
Ewe (including lambs at foot)	0.08	0.1	0.15
Ewe followers and store lambs	0.06	0.08	0.1
Dairy cow row	0.8	1.0	1.1
Suckler cow (including calf at foot)	0.7	0.9	1.1
Other cattle >24months	0.6	0.7	1.0
Weaned cattle <24 months	0.5	0.6	0.7
Equine	0.8	1.0	1.2
Other ruminants	lwt/650	lwt/650	lwt/650

Rates for rams and bulls should be as for mature females.

Values for young animals before weaning are included with their dams. After weaning, they should be calculated separately.

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Research material and advice provided by Mervyn Davies & Barbara McLean (ADAS).

Table F Liveweight categories for common domestic grazing livestock

Type	Breeds
Large ewe (>70 kg)	Bluefaced Leicester, Border Leicester, Cambridge, Charollais, Dorset Horn, Dorset Down, Greyface, Hampshire Down, Lleyn, Masham, Mule, NC Cheviot, Oxford, Scotch Halfbred, Suffolk, Texel, Lincoln longwool, Leicester longwool, Devon and Cornwall longwool, Dartmoor Greyface, Romney, Wiltshire Horn, Cotswold.
Medium ewe (50 kg - 70 kg)	*Cheviot, Hill Radnor, Whitefaced Woodland,* Devon Closewool, Jacob, Southdown, *Beulah Speckled Face,* Derbyshire Gritstone, Whitefaced Dartmoor, Norfolk Horn, Ryeland, *Lonk,* Kerry Hill, Llanwenog, *Scottish Blackface, Brecknock Hill Cheviot,* Clun Forest, *Rough Fell, Welsh Hill Speckleface.*
Small/Hill ewe (>50 kg)	*Dalesbred,* Exmoor Horn, *Herdwick, Swaledale, Welsh Mountain,* Portland, *Balwen, Badger Faced Welsh, Hebridean, Hill Radnor, Manx Loghtan, North Ronaldsay, Shetland, Soay, Black Welsh Mountain.*
Large dairy cow (> 700 kg)	Holstein, Friesian, Ayrshire, Dairy Shorthorn.
Medium dairy cow (500 kg - 700 kg)	Guernsey
Small dairy cow (< 500 kg)	Jersey
Large beef cow (>700 kg)	South Devon, Salers, Limousin, Simmental, Charolais, Sussex, Beef shorthorn, Lincoln, Hereford (regular).
Medium beef cow (500 kg - 700 kg)	Hereford (traditional), Gloucester, North (Ruby) Devon, Whitebred Shorthorn, A Angus (ordinary), Longhorn, Luing, Sussex, Welsh Black, *Blue-Grey.*
Small beef cow (< 500 kg)	*Galloway,* Dexter, *Highland, Belted Galloway,* Aberdeen Angus (original), Irish Moiled, Shetland.

Hill breeds are listed in italics.

Equines have not been included in this table due to the lack of reliable data on comparative breed sizes.

Appendix 4 The studies - methods

The background and methods of the studies that have passed the sifting process and have been subject to full quality assurance are summarised here. The findings are presented in the main body of the report. Where possible, stocking rates are presented as Livestock Unit equivalents based on the calculation method in Appendix 3.

Adamson & Kahl (2003) revisited ten long-term grazing exclusion plots in the North Pennines, many of which are reported at earlier stages, under other studies referred to here (for example, Rawes 1983). The plots covered a range of acid grassland and bog communities and calcareous flush on different soil types on Moor House NNR, ranging in altitude from 550-830 m above sea level. These have been in place for over 30 years. Control plots were identified adjacent to the exclosures. All were sampled systematically using point quadrats to record species cover. The change in vegetation over time was analysed. Only a comparison in vegetation characteristics could be made between grazed and ungrazed areas, as there is no data on livestock numbers or change over time.

Albon *et al.* (2007) in a large-scale correlative study of 11 large Deer Management Group areas in Scotland attempted to quantify the grazing and trampling impacts of a number of grazing animals, including sheep and deer, and to explore the relationship between impacts and stocking rates. Study areas were divided into 0.25 km^2 polygons and field indicators of grazing impacts were assessed within a range of habitat types within a polygon. This was used to generate a five point scale of impact for each habitat, following the methods of MacDonald *et al.* (1998). Study areas were either surveyed in full, or in stratified random polygons. Signs of occupancy of different grazing animals were identified in the field, and information on sheep and deer numbers were also collected at the estate level. A statistical model was developed to analyse the association between grazing animal and impact, controlling for environmental variables.

Amar *et al.* (2011) carried out a correlative observational study on moorland and rough grassland in Orkney, to examine whether reductions in sheep numbers had led to increases in hen harrier prey or preferred foraging, and whether sheep numbers or variations in weather condition had an effect on breeding success. Surveys were carried out on transects within 18 1 km squares. The presence of tall vegetation and droppings of vole and lagomorphs were recorded. Meadow pipits were surveyed along the same routes using standard methods. Hen harrier fledging data from long-term monitoring over 33 years was regressed against sheep numbers at the parish level from census data. Changes in the abundance of prey and the number of rough grassland quadrats were analysed.

Anderson & Radford (1994) in a targeted transect study of bare and eroded areas, examined vegetation change and colonisation following a reduction in grazing pressure on Kinder plateau, in the Derbyshire Peak District. This was a case study/survey approach with no control or comparison. Grazing pressure was estimated for the moorland area as a whole and not measured at the study transects. Pin frame point quadrats were used to measure vegetation composition along each transect, and biomass was sampled nearby. The study ran for 8 years.

Anderson & Yalden (1981) carried out a repeat mapping survey of heather moorland in the northern Peak District from aerial photography and field survey, and compared extent with a map made in 1913. Changes in parish level sheep numbers over the same period were assessed.

Baines (1996) attempted to investigate the role of grazing, via habitat structure, and predation, via game keeper activity, in black grouse breeding success. This was done using a survey approach to assess breeding bird and brood numbers on blocks of moors with each combination of light and heavy grazing (typical agricultural grazing regimes), and presence or absence of game keeping. The study covered five blocks of moors in Scotland and northern England. Levels of grazing were not assessed directly, although information on sheep and deer numbers was collected at the moor scale. Overall approximate grazing levels of 0.1 LU ha^{-1} yr^{-1} appear to be classed as ‘high’.

Bardgett *et al.* (2001) carried out a partially replicated and randomized study of successional transitions at two locations in northern England and one in Wales. Each transition consisted of six locations of varying semi-natural vegetation and inferred grazing intensity including *Festuca-Agrostis* (moderate- heavy grazing), *Nardus* (light-short-term ungrazed) and *Calluna*-dominated (long-term ungrazed) vegetation to oak-birch woodland (permanently ungrazed). Light grazing is quoted as 0.08-0.16 LU ha^{-1} yr^{-1}; moderate as 0.32-0.64 LU ha^{-1} yr^{-1}; and heavy as 0.64^{-1}.28 LU ha^{-1} yr^{-1}. At each site in the transition soils were sampled in three random replicate blocks. Soils were analysed for total carbon (C), nitrogen (N), microbial activity through phospholipid fatty acids (PLFA), C:N and fungal: bacterial ratio were calculated.

Britton *et al.* (2005) in a survey of montane habitat (*Racomitrium* and *Vaccinium* heaths) in Snowdonia, assessed the impacts of grazing pressure by measuring dung and monitoring plots for their vegetation composition and the condition of montane heath communities. Nutrient deposition effects were measured through soil and plant tissue chemistry.

Calladine *et al.* (2002) studied displaying black grouse males and female and brood density on ten paired sites in the North Pennines. Treatment sites were generally in agri-environment schemes with reduced sheep grazing on all or part of the study area (on average 1.1 sheep ha^{-1} (c. 0.1 LU ha^{-1}) summer compared with 2.4 (c. 0.22 LU ha^{-1}) at reference site, and 0.5 (c. 0.04 LU ha^{-1}) winter compared with 1.7(c. 0.15 LU ha^{-1}). Time since grazing was reduced varied between sites but was up to 5 years.

Clarke *et al.* (1995a, 1995b) in a replicated plot controlled-grazing experiment investigated the effect of size and distribution of grass patches in heather on the distribution of grazing animals. Deer and sheep, grazed alternately in each plot at similar grazing levels. Adjacent plots were grazed by different species at one time, to avoid the same species congregating along fences. A similar ratio of grass to heather was present in each plot, but at three configurations: one large, four intermediate or twelve small patches. A second experiment considered two different stocking rates of sheep, over three 14-day grazing periods in summer. They observed the locations of grazing animals daily during daylight in grass patches or heather in different distance zones from grass patches. In 1995b the animals were grazed over six grazing periods and the resulting utilization of, and impact on, heather was measured at fixed points on transects covering the different zones Mean utilization was calculated for different zones, for each grazing period.

Clay *et al.* (2009) investigated the hydrological responses to burning and grazing treatments at Moor House NNR in the North Pennines. The study used the partially randomized, replicated Hard Hill plots, reported in other studies (for example, Rawes & Hobbs, 1979; Adamson & Kahl, 2003). The study area consists of four replicates of three burning treatments, 10-year, 20-year and unburned, in combination with either grazing or no grazing, applied factorially. However, only two replicates were used in this study. Grazing is the background level for the grazing unit, estimated as 0.6^{-1} Swaledale sheep per ha in summer (0.03-0.05 LU ha^{-1} yr^{-1}), although the actual level on the plots is estimated at less than 0.1 sheep in summer (0.005 LU ha^{-1} yr^{-1}) (Adamson & Kahl, 2003). All plots were burned in 1954, after which the regimes were established. The work reported here is a continuation of the studies by Worral *et al.* (2007, 2008), extending the number of visits from 16 to over 50 over more than two years. Depth to water table was measured in the same set of dipwells over a three year period. Burning took place on the 10-year treatment during the study, giving before and after measurements. Data was similarly normalized against a grazed/unburned control. Runoff was also measured from three crest-fall runoff traps per plot, inspected once per month. Results were analysed factorially and the significance of each factor tested. Parameters of preceding rainfall events were included in the analysis of runoff and management treatment.

Cole *et al.* (2010) compared habitat characteristics and their influence on invertebrates in two large plots (>40 ha), one grazed year round (0.3 LU ha^{-1} yr^{-1}), and one grazed in summer only (0.08 LU ha^{-1} yr^{-1}), at Sourhope Research Station in the Scottish Borders. The vegetation consisted of bracken over *Agrostis-Festuca* grassland, in a mosaic with *Nardus* grassland in the summer only plot. In each plot 15 sample locations were chosen to represent the range of altitude, habitat type and structure. At each location a row of 9 pitfall traps, 2 m apart, were established. Traps were left in situ for four weeks in summer, and key groups of invertebrates identified and size distribution examined. Vegetation was mapped in a 30 m zone round each line of traps, and GIS used to draw ellipses at four scales between 0.25 m and 5 m. Data for 30 continuous habitat variables encompassing habitat composition and structure were used to identify significant effects on three groups of invertebrates (mobile arthropods, immobile invertebrates and carabids) at the different spatial scales.

Common *et al.* (1998) in a replicated paddock experiment explored *Nardus* utilisation by lactating cattle at different stocking levels, and the resulting effects on animal performance and floristic composition. Two treatments were implemented based on target sward heights (4-5 cm and 6-7cm), grazed with spring-calving blue-grey cattle and their Charolais-cross calves over five years. The mean stocking rates over the five years were 0.45 (0.37-0.57) LU ha^{-1} yr^{-1} for the shorter sward and 0.27 (0.22-0.36) LU ha^{-1} yr^{-1} for the taller treatment. Levels of *Nardus* utilisation and diet composition of animals, sward height and floristic composition and size of *Nardus* tussocks were measured twice weekly in thee grazing season. Animal performance in terms of milk production and live-weight were monitored.

Cooper *et al.* (1996) carried out a correlative study of the distribution, composition and management of heath and mire vegetation in the Northern Ireland uplands. Six upland areas were identified, based on the extent of statutory designations. The extent of heath and mire communities were mapped in the field, in a stratified random sample of 628 x 25 ha squares, based on land cover classes from the Northern Ireland Countryside Survey. Species data and environmental management variables, including grazing pressure assessed as high, medium or low, were recorded in quadrats at two scales. Ordination techniques were used to identify environmental variables. This explained the greatest variation in mire vegetation quadrats and the significance of these relationships was examined by regression analysis.

Critchley *et al.* (2008) in an unreplicated large paddock study assessed the effect of two sheep-only and two mixed (cattle and sheep) grazing regimes on vegetation and livestock performance when applied to heterogeneous degraded wet heath at Redesdale experimental farm, Northumberland. The four treatments were:

1) Low sheep (0.66 sheep ha^{-1} minus 25% Oct-Feb inclusive; 0.06 LU $ha^{-1}yr^{-1}$).
2) Low sheep plus cows (as 1 sheep ha^{-1} plus 0.75 cows summer only; 0.29 LU $ha^{-1}yr^{-1}$).
3) High sheep (1.5 sheep ha^{-1} minus 25% Oct-Feb inclusive; 0.13 LU $ha^{-1}yr^{-1}$).
4) High sheep plus cows (as 3 sheep ha^{-1} plus 0.75 cows summer only; 0.36 LU $ha^{-1}yr^{-1}$).

The breeds used were Scottish blackface sheep and Holstein cattle crossed with Belgian blue and Simmental. The sheep grazing regimes had been in place for a number of years before the start of this study, with cattle grazed in summer for the four years of the experiment. Species cover, sward height and grazing indices were measured each year, along with livestock liveweight.

DeGabriel *et al.* (2011) studied the effects of reduction or removal of sheep grazing on estates in the Scottish Highlands. Sites ranged from 148 km^2 to 1,611 km^2 and eight pairs were selected which had been subject to previous habitat assessment. Sheep were removed from one of the sites in each pair, and at two sites sheep grazing was reduced at the grazed site of the pair, but these were still grazed at commercial rates. Previous grazing at all sites had been at commercial rates, and red deer were present at all sites. Within each site up to four 0.25 km^2 squares were selected on the basis of over 50% heather cover, and three 10 m x 10 m plots established within these squares at random. Plots were visited in spring and summer in one or two years and the density of domestic and wild herbivores was estimated from dung counts. Vegetation heights were measured systematically and type was recorded, and heather cover and utilization was assessed. Shannon-Weiner diversity indices were calculated from vegetation data, and models were developed to test the effects of herbivore, habitat and environmental variables on grazing impacts and alpha and beta diversity.

Deléglise *et al.* (2011a) compared species diversity (richness and evenness) and vegetation spatial heterogeneity of subalpine grassland communities between replicated traditionally grazed plots and their long-term (>20 years) ungrazed equivalents. The study took place in the western French Alps.

The communities are described as calcareous, mesic and heath grassland. There were three replicates of each plot, with the grazed plots open to the prevailing agricultural grazing. The pairs were said to be similar to each other at the time of grazing exclusion, but were up to several kilometres apart. Vegetation was sampled at seven spatial scales, from 5 cm x 5 cm to 1m^2. Species ground cover was assessed along with leaf traits: specific leaf area; leaf dry matter content; leaf nitrogen and carbon content. A number of quadrat and spatial variables were derived and tested against grain size for grazed and ungrazed plots in each grassland type.

Deleglise *et al.* (2011b) in the same study areas examined spatial patterns of species traits with grazing exclusion, and whether exclusion leads to an increase in patch size of vegetation and contrast between patches. Canopy height was measured and ground cover measured in contiguous small quadrats on two perpendicular transects crossing in the middle of the plot. Plant traits of vegetative height, specific leaf area, leaf dry matter content and leaf nitrogen content were measured in each community.

Dennis *et al.* (1997) investigated the effects of different grazing treatments on epigeal beetles in *Nardus*-dominated grassland vegetation at Blackdean Curr, Cheviot Hills, Northumberland. Treatments were sheep, and sheep plus cattle, grazed to achieve between-tussock heights of 4-5 cm (stocking rate approximately 0.3 LU ha^{-1} yr^{-1} sheep and 0.4 LU ha^{-1} yr^{-1} sheep and cattle) and 6-7 cm (approximately 0.15-0.2 LU ha^{-1} yr^{-1} sheep and 0.2-0.25 LU ha^{-1} yr^{-1} sheep and cattle). There was also an ungrazed control with an average sward height 8-12 cm. All treatments were replicated twice to give a total of 10 plots, varying in size to accommodate six yearling steers in the mixed livestock treatments from June to August each year. Sheep numbers per plot were adjusted weekly to maintain target sward heights. Whilst data on stocking rates for each plot was recorded and used in analyses in this and related studies, it is not presented in sufficient detail to present here. Beetles were sampled from 12 randomly located pitfall traps per plot, over two summers. Sward heights were measured on radial transects in the vicinity of traps, twice weekly. Botanical composition was assessed twice during each growing season and diversity indices calculated.

Dennis *et al.* (2001) also studied the effects of the grazing treatments on epigeal spiders, harvestmen and pseudoscorpions. In addition to pitfall traps, monthly suction sampling and visual searches for spiders' webs were used to collect species. Sampling took place in the 3rd and 4th year of grazing treatments. Pitfall catches were combined for each plot to remove variation in capture efficiency related to location. The findings were analysed factorially against livestock treatment and target sward height using analysis of variance. Multivariate techniques were used to calculate the variability in arachnid species/abundance accounted for by botanical composition, vegetation height and stocking rate.

Dennis *et al.* (2002) from the same controlled grazing experiment described above investigated the spatial distribution of upland beetles in relation to landform, vegetation and grazing management. The abundance of selected species in the pitfall traps was analysed spatially using distance statistic techniques to explore the location and degree and scale of spatial aggregation of each species. Stepwise selection and multiple regression techniques were used to relate the degree of spatial aggregation to different plot characteristics including topography, vegetation structure and diversity, as well as overall stocking rate. Sampling took place in the 3rd and 4th year of grazing treatments.

Dennis *et al.* (2008) investigated the effects of a range of grazing treatments on foliar arthropods. Sampling was carried out by suction, on a systematic grid, and by sweep netting on transects. Sampling took place over three years, with an additional vacuum sample in 2002 forming a baseline before autumn cattle grazing in the mixed treatment.

This was one of a number of publications that emerged from a controlled grazing experiment on the impacts of sheep and cattle grazing on biodiversity, mainly birds and invertebrates, at Glen Finglas in Scotland. Many of the invertebrate groups studied are important prey for moorland birds. It is described in detail here, and related studies are cross-referenced. The experiment involved 24 grazing enclosures, on upland acid grassland and mire communities, measuring 3.3 ha each. There were four grazing treatments with six replicates of each. These were positioned in three blocks of two randomized replicates each, located in different parts of the estate and approximately 5 km from each other.

The grazing treatments were:

1) 9 sheep per enclosure (c. 0.17 LU ha^{-1} yr^{-1});
2) 3 sheep per enclosure (c. 0.06 LU ha^{-1} yr^{-1});
3) 2 sheep per enclosure with, for four weeks in autumn, 2 cows each with a suckling calf (c. 0.08LU ha^{-1} yr^{-1}); and
4) ungrazed.

Treatment 1 was regarded as high-intensity grazing. Treatments 2 and 3 were each low-intensity grazing regimes and were designed to be equivalent in terms of off-take, although are slightly different when expressed in LU terms using the methods in Appendix 3, and equivalent to grazing pressure at the site before the experiment commenced. The sheep used were Blackface and Swaledale/Blackface cross hogs (one year old ewes) and the cows were Luing and Luing/Simmental crosses. Livestock were in the plots from April to December each year except for during essential farming practices such as dipping, shearing and tupping.

Baseline data on plants, invertebrates and breeding birds were collected within the plot areas but before the erection of the fences in 2002. Grazing treatments were applied from 2003 onwards. Prior to this the whole moorland unit was grazed at a rate similar to that achieved under treatment 2, on an annual average basis.

Douglas *et al.* (2008) investigated foraging habitat selection and nestling diet of meadow pipits in the most intensively grazed treatment at Glen Finglas (see Dennis *et al.* 2008), in the season after treatments commenced. Therefore only the high intensity or ‘commercial’ treatment (1) was used. Nests in the treatment plots were located, and foraging behaviour observed from portable hides. The spot where birds were last observed before returning to the nest with food was regarded as a foraging site (2 m x 2 m square). Prey items and size were identified as far as possible using telescopes. Each foraging square was paired with a random control square. Invertebrates were sampled by sweep netting and turf stripping, and vegetation height and density measured in each sample and control square.

Evans *et al.* (2005) in the season following establishment of the experiment at Glen Finglas (see Dennis *et al*. 2008) studied the effect of the grazing on meadow pipit egg size. Breeding meadow pipit territories were identified using Common Bird Census (CBC) techniques, and nests located. Measurements were made of each egg, and nests observed regularly to monitor egg and nestling fate.

Evans *et al.* (2006a) examined the effect of treatments at Glen Finglas (see Dennis *et al.* 2008) on meadow pipit breeding success. The study had run for three years when reported. In treatment 3 the first year represented low intensity sheep only, before cattle were introduced in autumn 2003. Cattle grazing days in this treatment were calculated, as the period varied between years. Breeding territories were mapped in each plot, and breeding behaviour recorded. Pakeman (unpublished data) has provided continuation data up to 2011, and some commentary on the treatment responses, along with additional information from botanical monitoring of *Agrostis-Festuca* grassland.

Evans *et al.* (2006b) studied the effects of the grazing treatments at Glen Finglas (see Dennis *et al*. 2008) on field vole populations. Signs (runways, fresh clippings and fresh droppings) were searched for in randomly-placed quadrats in each treatment, twice per year for three years.

Evans (1977) investigated links between sheep grazing pressure and soil erosion in a catchment-scale correlative study in the northern Peak District. The catchment vegetation consists of acid grassland of varying dominance, and heather and bilberry on generally less well drained peaty soils. Thirty-one areas of bare ground were subjectively selected and measured over a two year period, and sheep counted in the catchment at regular intervals. Study areas were subjectively chosen to include a range of sizes, weighted towards larger erosion scars. Erosion rates were measured objectively using pins and nail markers to measure surface lowering and bare ground extent, and soil was collected downslope in traps. A follow up study took place six years later, following changes in sheep numbers in the catchment.

Evans (2005) updated the findings from monitoring the same Peak District catchment over a further three decades, and made comparisons with erosion on a nearby higher and more exposed slope (Back Tor). During the intervening period sheep numbers were further reduced and stabilised through conservation measures. The catchment was visited eight times over a thirty year period, taking a route that involved visiting the original erosion scars. Back Tor was also visited and scars photographed.

Ferriera *et al.* (2005) in an unreplicated single paddock experiment in NW Spain investigated the diet composition of goats and sheep grazing together on gorse-heathland on two grazing dates, with different availability of preferred species (perennial rye-grass). The site was upland, at 1000 m asl. and stated as gorse heath with patches of grass and clover. An area of 5 ha of perennial rye-grass *Lolium perenne* was sown in the 22 ha paddock. Sheep and goats were grazed at the same numbers at the same time, with faeces sampled at two points at the start and end of July, and calibrated with faecal recovery values obtained from previous validation pen studies with animals fed diets of known proportions of the main plant species.

Fisher *et al.* (1994) in an unreplicated paddock experiment in Perthshire, Scotland, compared goat, sheep and mixed grazing on semi-natural hill grassland with remnant dwarf shrub and mire communities. Paddocks were grazed in summer, and height measurements of eight graminoid and shrub species made every 10 days through the grazing period.

Fraser *et al.* (2009) tested the effects on diet selection by cattle and sheep grazing two contrasting heathland communities with low (8%) and high (61%) cover of *Calluna*. The two study areas were sub divided into four x 1ha plots and grazed by Welsh mountain sheep, Scottish blackface sheep, Welsh black cattle and Continental cross (Holstein x Belgian blue and Holstein x Simental) cattle. Six mature barren females of each breed were used, with animals treated as replicates. Each breed/species was randomly assigned to a sub plot at the beginning of the measurement period then moved to the next sub plot daily. Since the focus of the study is diet selection with the animals effectively the study unit and rotated around plots, it is not meaningful to compare annual average stocking rates per plot. The grazing was carried out on the low heather-cover plot over a one week period in both July and September 2004 and on the high heather-cover plot for one week in July and September 2005. The two areas were analysed separately due to the different grazing periods. Animal diet composition was sampled, and botanical composition and biomass measured in each plot. The Continental cross cattle had to be excluded from the low site study on welfare grounds.

Fraser *et al.* (2011) in a study at Pwllpeiran Research Farm, mid-Wales, tested the effects on sward composition and animal performance of long term grazing by cattle and sheep of *Molinia*-dominant grassland. Three treatments, summer cattle grazing, summer sheep grazing, and no grazing, were applied to 2 ha plots on grassland which hasn't been grazed for over 20 years. There were two replicates of each treatment grazed by yearling Welsh black heifers or Welsh mountain hoggs. The two species were grazed at equivalent stocking rates (around 0.2 LU ha^{-1} yr^{-1}), and for the same period in each year, and grazing stopped when *Molinia* utilisation in a plot reached 50%. Botanical composition and sward heights, *Molinia* utilisation and biomass and livestock weight and condition scores recorded at beginning and over time in each treatment. The experiment ran for eight years.

Fryday (2001) studied the effects of grazing removal on lichen amount and growth in montane habitats. The study focussed on long-term exclosures at Moor House NNR, Upper Teesdale, northern England; Inchnadamph NW Scotland; and Crib Goch, Snowdonia, Wales. The plots have been in place for up to 40 years, as at Moor House. This was a basic comparison of lichen frequency and biomass inside the exclosures with the grazed areas outside. Background grazing levels were not given.

Gardiner *et al.* (2002) reported two experiments at Pwllpeiran Research Farm, mid-Wales, investigating the effects of stocking rate and timing of grazing on degraded heather and grass dominated moorland plant communities. In experiment 1, Cambrian Mountains ESA (CMESA) tier 1 (1.5 sheep ha^{-1}; 0.12 LU ha^{-1} yr^{-1}) and tier 2 (1 sheep ha^{-1}; 0.08 LU ha^{-1} yr^{-1}) stocking rate prescriptions were each applied to one paddock of *Calluna-Nardus* dominated vegetation and one paddock of *Agrostis-Festuca* dominated vegetation, i.e. four unreplicated treatment combinations in total (0.084 LU ha^{-1} yr^{-1} and 0.06 LU ha^{-1} yr^{-1} for tier 1 and tier 2 respectively on *Calluna-Nardus* paddocks and 0.11 LU ha^{-1} yr^{-1} and 0.07 LU ha^{-1} yr^{-1} on *Agrostis-Festuca* paddocks, adjusting for off-wintering periods) . Sheep were Welsh mountain. These paddocks had originally been established in 1990 and grazed at the original CMESA rates set for each paddock (ranging from 0.07 LU ha^{-1} yr^{-1} on *Calluna-Nardus* to 0.16 LU ha^{-1} yr^{-1} on *Agrostis-Festuca* vegetation) until 1995.

In experiment 2, the following five grazing treatments were applied to one unreplicated 2ha paddock each of *Vaccinium-Nardus* vegetation, based on original CMESA rates. The actual rate achieved over the grazing period is given:

1) Tier 1A stocking prescription (0.18 LU ha^{-1} yr^{-1}) applied between April-October (0.24 LU ha^{-1}).
2) Tier 1A stocking prescription (0.18 LU ha^{-1} yr^{-1}) applied between April- July (0.48 LU ha^{-1}).
3) Tier 2A stocking prescription (0.12 LU ha^{-1} yr^{-1}) applied between April-October (0.15LU ha^{-1}).
4) Tier 2A stocking prescription (0.12 LU ha^{-1} yr^{-1}) applied between April- July (0.3 LU ha^{-1}).
5) An ungrazed paddock.

An additional 5 paddocks were added in 1995 to look at seasonal application of the revised CMESA tier 1 (1.5 sheep ha^{-1}; 0.12 LU ha^{-1} yr^{-1}) and 2 (1 sheep ha^{-1}; 0.08 LU ha^{-1} yr^{-1}) stocking rates to previously ungrazed *Vaccinium-Nardus* vegetation, plus a lower rate of 0.5 sheep ha^{-1} (0.04 LU ha^{-1} yr^{-1}) on previously grazed and ungrazed vegetation. With adjustments for off-wintering in the system this became 2.0, 1.3 and 0.7 sheep ha^{-1} (0.16, 0.1 and 0.06 LU ha^{-1}) applied over a six-month period, with the two latter doubled and applied over a three-month period in two treatments. Again these treatments were unreplicated.

In addition to species composition and cover at fixed points, grazing the incidence of grazing on *Calluna*, *Vaccinium* and *Nardus* was measured. Seed bank germination studies were also carried out.

Garnett *et al.* (2000) examined the effects of grazing and burning on carbon sequestration on the Hard Hill plots on blanket mire at Moor House NNR (see Clay *et al*. 2009). This study sampled the 10-year burned and grazed treatments, and the long term unburned, both grazed and ungrazed treatments. Carbon content was assessed from peat cores. Accumulation was measured using spheroidal carbonaceous particle (SCP) determination techniques to identify a 'take-off' point as a chronological marker above which accumulation could be measured. Charcoal concentration profiles were also assessed to give chronological information.

Gordon *et al.* (2001) investigated the interaction of grazing and nutrient addition on the four grazed and one ungrazed plots used for Gardiner *et al.* (2002) as described in their experiment 2. Nutrient addition took place on two grazing treatments, ESA tier 1 stocking rate over three months, and tier 2 rates over 6 months. Sheep used were Welsh mountain and Welsh hill speckled face ewes. Non-breeding ewe lambs were grazed until August, when they were replaced with dry ewes after weaning. In one year Scottish blackface ewes were grazed. N addition treatments were 10 and 20 kg ha^{-1} yr^{-1} as ammonium sulphate and 20 kg ha^{-1} yr^{-1} as sodium nitrate, added fortnightly to replicated plots over four years. Vegetation composition and biomass was sampled, and N mineralisation measured from soil cores. Soil water nitrate and ammonia, and gaseous fluxes were measured. Comparisons were made along transects with adjacent ungrazed areas.

Grant (1968) studied the regeneration of heather on areas burned as part of a management programme at 30 sites in south, central and east Scotland. At each site sheep were excluded from part of the burned area. All sites had at least 75% heather cover and were burned in spring, and all were grazed at the background agricultural grazing levels, with no figures given. The age at burning was recorded, and heather regeneration, with heights and species composition, were monitored over time, for up to eight years.

Grant & Hunter (1968) investigated the interaction of heather burning and grazing in an unreplicated small plot experiment in north-east Scotland. Six grazing treatments were applied: low summer and low winter, both equivalent to 0.05 LU ha^{-1} yr^{-1}; low summer and winter, 0.09 LU ha^{-1} yr^{-1}; high summer and high winter, both equivalent to 0.14 LU ha^{-1} yr^{-1}; and high summer and winter, 0.28 LU ha^{-1} yr^{-1}. Grazing was applied over three periods for each season, with the high treatments applied at three times the duration or numbers than the low treatments. Each plot was sub-divided into four sub-plots, with sub-plots burned at two-yearly intervals, with stock having equal access to the different aged heather in a paddock. From year 7, after all burning had taken place; sheep locations were recorded three times per day. Botanical composition was recorded from point quadrats in each sub-plot, and heather growth measurements made in the final year.

Grant *et al* (1985a) imposed controlled sheep grazing treatments on three 0.1 ha plots at each of three sites on blanket bog at Lephinmore, Argyle, Scotland. Two of the sites had been burned within the previous two years, and the third site had not been burned for ten years at the start of the study. One recently burned site and one site with older heather were grazed year-round except for four weeks in spring and ten weeks in Oct-Dec. The three grazing treatments imposed were low:0.06 LU ha^{-1} yr^{-1};intermediate: 0.14 LU ha^{-1} yr^{-1};high: 0.22 LU ha^{-1} yr^{-1}). A third recently burned site was not grazed from December to April (Low: 0.04 LU ha^{-1} yr^{-1}; intermediate: 0.08 LU ha^{-1} yr^{-1}; high: 0.13 LU ha^{-1} yr^{-1}). Plots with similar treatments could not be considered as replicates. To achieve the desired grazing levels, 3-4 sheep were grazed at monthly intervals for 1-3 days. Animals were rotated around the plots and held on an adjacent paddock for one week prior to each grazing period. Mature Scottish Blackface ewes were used in the first year, and wethers in subsequent years. Sward composition, density and biomass were assessed at three-yearly intervals by restricted random sampling. The treatments were in place for 11 years.

Grant *et al.* (1985b) carried out a controlled grazing study to compare diet selection of sheep and cattle on a range of moorland acid grassland communities. Sites were in the Cleish Hills, Fife, and Wauchope Forest, Roxburgh, both Scotland. Mixed groups of blue-grey and Hereford x *Friesian* cattle and Scottish blackface sheep were allocated to 3 ha plots of *Agrostis-Festuca*, *Nardus* (with *Festuca* and *Deschampsia*) or *Molinia* grassland. All sites had previously been lightly grazed, with the *Agrostis-Festuca* plot recently limed, and the *Molinia* plot burned. Grazing took place over three seasons, with animal groups allocated to sites randomly in each year. Plots were grazed for two six-day periods at different times between early summer and autumn, with animals first initially grazed on adjacent 'run-in' plots. Although there is a degree of variability the annual average stocking rate on each plot was around 0.12 LU ha^{-1} yr^{-1}, although at least in the first year plots received additional grazing outside of the measurement periods to achieve the desired sward condition. Diet samples were obtained from animals on three days, and measured for digestibility and composition. Biomass was sampled in each plot, and botanical composition sampled from point quadrats. Similarity coefficients were calculated to compare species diet, and diet with botanical sward composition.

Grant *et al.* (1987) investigated diet selection and nutrient intake of sheep and cattle grazing together on two dwarf shrub communities: a bog community at Lephinmore, Argyll; and a dry heath community at Glensaugh, East Grampians, both in Scotland. One un-replicated 3 ha plot at each site was grazed with 11 barren suckler cows (blue-grey and Hereford x Friesian) and 10-13 barren blackface ewes. Treatment plots were grazed for 6 days in each period following six days on adjacent "run-in" plots. The annual average stocking rate on each plot was around 0.12 LU ha^{-1} yr^{-1}. There was a degree of randomization in the combinations of individual animals and grazing periods across this and other experiments (Grant 1985b). Each plot was subject to 4 (bog) or 5 (heath) grazing periods at different times of year. Diet samples were taken from 3-4 animals of each species during each grazing period, and biomass, species composition and sward height was measured.

Grant *et al.* (1996a) in an un-replicated paddock experiment compared two levels of defoliation of *Molinia* (33% and 66%; identified as lamina lengths of 10-12 cm and 5-6 cm respectively) by cattle in summer, at two sites in central and southern Scotland, over a six-year period. Ungrazed areas were replicated in each paddock, and there were replicated tussock clipping experiments, to the same levels of defoliation, over three years at both sites. Random measurements of leaf extension and biomass were made in each paddock, and vegetation composition and cover recorded from point quadrats.

Grant *et al.* (1996b) in a similar un-replicated paddock experiment in central Scotland investigated controlled grazing by sheep, cattle and goats on *Nardus*. The paddocks were stocked throughout the growing season to achieve an inter-tussock sward height of 4-5 cm for cattle and either 3-4 or 4-5 cm for sheep. A second experiment had three goat treatments (4-5 cm, 5-6 cm, 6-7 cm) and a sheep control (4-5 cm). Plot sizes were such that a minimum of three animals were grazed per plot to achieve the target heights. Between tussock biomass measurements were made three times per year, and from a sample of *Nardus* tussocks at the end of the year. *Nardus* utilisation was measured on a sample of tillers. Leaf extension was also measured on a number of protected tillers. Vegetation composition was assessed from point quadrats.

Hartley (1997) studied the interaction of grazing and nutrient addition on the competitive balance between heather and grasses, and whether grazing is concentrated in areas of high plant and soil nutrients. Four treatment blocks were established at each of two sites in the Grampian Mountains, Scotland. Two blocks were fenced to exclude grazing and two were open to the prevailing farm grazing regime. Eight nutrient treatments in total (75 kg ha^{-1} yr^{-1} N, 12.5 kg ha^{-1} yr^{-1} P, 25 kg ha^{-1} yr^{-1} K alone or in combination, and zero addition) were applied to both a fenced and unfenced plot at each site – so each plot has four treatments applied and each grazing/nutrient combination is applied once at each site. Measurements of *Calluna* height and cover, and proportion of shoots grazed were made in three 1 m^2 quadrats at each treatment plot, over three years, along with plant and soil nutrient concentrations.

Hartley & Mitchell (2005) Established an experiment in two areas of Scotland to look at the effects of nutrient addition of N, P and K alone or in combination, with and without grazing (grazing was the prevailing farm grazing levels, so considered only as presence/absence) on mosaics of dwarf shrub and grass.

Hester & Baillie (1998) examined the spatial use of fragmented heather moorland and the impacts on vegetation by red deer and Scottish blackface sheep, in a replicated controlled grazing experiment at Glensaugh, north-east Scotland. Six 1 ha paddocks were established on heather-dominated moorland with approximately 15% *Agrostis-Festuca* grassland in each. The treatments consisted of two replicates each of 12 sheep or eight deer per plot (to give comparable total off-take), or mixed sheep (6) and deer (4). Animals were grazed for two months in autumn of the first year, two months in summer of the second year and two four week summer periods, with a six-week gap, in each of the following three years. The overall annual stocking rate was 0.18 LU ha^{-1} yr^{-1}. Two smaller ungrazed controls were also established and all plots fenced against rabbit grazing. The plot size was believed to give effects similar to animals grazing on the open hill. Vegetation height and heather condition were measured throughout, and heights, species composition and heather utilization measured at the end of grazing periods. Measurements were made along permanent transects placed on each of four randomly selected grass patches in three size classes, and on four areas distant from grass patches. The development of paths from grass patches was also monitored.

Hester *et al.* (1999) in the same experiment observed the locations of grazing animals during daylight hours. The location and behaviour of each individually marked animal was recorded at half-hourly intervals by telescope scan. A second set of observations involved detailed recording of behaviour and movement of a single animal over a 15-minute period. Both types of observation were made on two days per week during the grazing periods, after a one-week settling in period. Bite rates were also measured on one occasion and pellet groups were counted in random quadrats, with patch size recorded for grassland quadrats.

Hetherington (2000) investigated the use of feed blocks to manage grazing on semi-natural rough grazing at four sites in the Cambrian Mountains, Wales. All sites were grazed by Welsh mountain ewes at ESA prescription rates, and vegetation consisted of mosaics of *Nardus* grassland with

Vaccinium and *Calluna*, ranging from 15 ha - 55 ha in size. Two control sites continued typical practice, ie placing feed blocks at points identified as convenient by the farmer, and two sites had feed blocks placed at the centre of randomly identified 50 m^2 experimental areas within the *Nardus*/ *Vaccinium* area. Blocks were placed twice in each area, in April-May and October-November of one year. Within each experimental area, vegetation cover and structure measurements were made in survey plots 12 x 4 m^2, three of which were fenced against grazing. Similar experimental areas were established in the control sites. Structure and composition in grazed and ungrazed areas were compared, along with incidence of grazing on dwarf shrub, and frequency of dung in relation to distance from the centre of the experimental areas with blocks and in control sites.

Hill *et al.* (1992) reported the long-term effects of removal of grazing in exclosures at nine sites on a range of soil and vegetation types in Snowdonia, N Wales. Experiments originally also included grazing treatments, but the exclusion treatments were expanded and continued for longer. Length of time since stock was excluded varied between sites, and was 13-24 years at time of study. Summer stocking rates outside the exclosures were estimated at 0.4 LU ha^{-1} on brown earths to 0.15 LU ha^1 at the highest altitude site. Plots were replicated and the prevailing agricultural grazing regime in open plots provided controls. Vegetation cover was measured from point quadrats and biomass was sampled.

Hodgson *et al.* (1991) in the same experimental areas as reported in Grant *et al.* (1985b) and Grant *et al.* (1987), above, compared the ingestive behaviour and herbage intake of sheep and cattle grazing the range of acid grassland and dwarf shrub bog communities, and an established sown productive sward. The areas were grazed by a mixed group of Blue-grey and Hereford x Friesian cows and Scottish blackface sheep, all barren, with prior experience of grazing the vegetation types. Groups of nine to eleven cows and ten to thirteen ewes were rotated around the plots in two week periods, generally giving two grazing periods on each plot per year. Organic matter intake and digestibility were measured in diet samples from fistulated animals, and faecal outputs measured on different animals. Herbage-mass measurements were also made of botanical composition and canopy structure.

Hope *et al.* (1996) studied the effects of sheep reduction and removal on large areas of the Scottish Highlands on common semi-natural upland vegetation communities, and on the main wild vertebrate herbivores associated with them. Eleven pairs of sites were identified, with one of each pair grazed at the prevailing grazing levels. Sheep grazing had been removed or reduced for up to 25 years on the treatment sites. Vegetation composition and structure, herbivore dung and signs of vole presence were sampled by constrained random sampling, with $6^{-}18$ plots per vegetation type in each study area. Difference in vegetation attributes including patch size between control and reduced grazing areas were tested as were pellet groups for different grazing species. Vole run frequency was tested against vegetation attributes.

Hulme *et al.* (1999) considered the effect of controlled sheep grazing on the dynamics of *Agrostis-Festuca* grassland at two sites, one with on podzolic soils with a higher initial cover of less preferred *Nardus stricta* and *Molinia caerulea* and the other on more productive brown earth soil. Three sward height treatments (3 cm, 4.5 cm, 6 cm) were imposed through the summer grazing period with comparison ungrazed areas in each treatment plot, with each treatment replicated twice. All plots were grazed by Scottish blackface wethers.

Hulme *et al.* (2002) implemented the following grazing treatments on a wet heath system with degraded heather, at Redesdale in Northumberland: summer, winter and year-round low sheep grazing (0.7 sheep ha^{-1}; 0.06 LU $ha^{-1}yr^{-1}$), and year-round moderate (1.4 sheep ha-; 0.11 LU $ha^{-1}yr^{-1}$), in two replicate blocks. The control was the existing heft regime of 2.1 sheep ha^{-1} (0.17 LU $ha^{-1}yr^{-1}$). Each treatment plot had an ungrazed fenced exclosure. Heather utilisation, vegetation composition and height were measured over 6 years.

Hunter & Milner (1963) tested the behaviour of individual sheep and related groups of South Country Cheviot hill sheep. Two sheep were chosen at random from three home range groups, identified by the shepherd, from the flock of 150 (overall stocking rate 0.15 LU $ha^{-1}yr^{-1}$). Nine family groups were also studied, identified by marks. The positions of individual marked sheep were recorded hourly from dawn to dusk on one day per week during September to March over one winter period. The locations of each of the family group members were also recorded using similar methods over a one year period from September to August, and the location of the wider flock monitored hourly over a three year period (instrumentation was used to monitor locations of all groups and individuals, but not fully described here).

Jewel *et al.* (2005) in an unreplicated paddock study investigated the effects of re-introducing cattle to an alpine pasture system in Switzerland. The pasture consisted of *Calluna-Vaccinium* heath and variants of *Nardus* grassland, and was typical of abandoned pastures in the area. The 73 ha pasture was split in two and grazed with 40-60 Highland cattle in summer, which were moved between the two paddocks in July. In the later years the two paddocks were run together. Vegetation was sampled on parallel transects across the slope at 50 m altitude intervals, and biomass sampled from random points in two years. Soil samples were also taken. Cattle grazing behaviour was also observed over a period of a 6-8 days in each of two years. The relationship between grazing pattern and vegetation type was explored.

Jenkins & Watson (2001) on an estate in Angus, east Scotland investigated changes in bird populations with an increase in grass at the expense of heather moorland, as a result form a shift from grouse shooting towards sheep grazing. Moorland birds were surveyed over a number of units on the estate in three years in the 1990s, and compared with surveys undertaken during 1957-61. In the intervening period some units had been largely converted from heathland to grass. Survey methods differed between periods, with dogs used to flush birds in the earlier surveys, but remote observation used more in the later surveys.

Johnston (2012) collated and summarized agri-environment site information on mean annual and seasonal stocking rates and site condition. Condition data is generally taken from Common Standards Monitoring using a structured, largely visual, assessment rather than quantitative monitoring. The moorland units reported cover a significant area of the Lake District Fells (c 30,000 ha). Agreements have been in place for up to 14 years, with most around 10 years old.

Keiller *et al.* (1995) studied the effects of long-term grazing exclusion on upland arthropod communities at sites in Snowdonia and mid-Wales (Pwllpeiran Research Farm). The vegetation at the Snowdonia sites was *Nardus-Festuca* on podzolic soils with heathy vegetation in the grazing exclosure, and *Agrostis-Festuca* on brown earths. The mid-Wales study site was on a peaty-podzol soil. Grazing has been excluded for 16 and 35 years at Snowdonia sites, but only 3-4 years at mid-Wales. As part of a controlled grazing experiment comparison areas are grazed at the open hill grazing levels in Snowdonia, and ESA stocking rates applied for different periods in mid-Wales. Invertebrates were sampled over 1 year using pitfall and emergence traps.

Kirkham & Milne (2000) studied the response of heather to variations in grazing intensity, location and development phase, in the same six upland regions of England and Wales as reported in Milne *et al.* (2002). In each region sites were chosen to represent a range of grazing intensities on each heather growth phase. The proportion of shoots grazed (Grazing Index) was measured at each site. Comparisons were made in the weight of shoot growth in sample areas protected from grazing during the growing season with those of longer-term ungrazed plots. Woody material was also measured, and all measurements adjusted to 100% cover. Measurements were made in each of three years. Soil and altitude variables were recorded, to test for their effects.

Lawrence & Wood-Gush (1988) investigated the home-range behaviour and social organisation of Scottish blackface sheep. They aimed to test to what extent group structure and home ranges exist within sheep social organization. A flock of 62 ewes were studied on an area of 110 ha in the Pentland Hills, Lothian. Older ewes were removed from the flock in September and replaced by ewe lambs. All sheep were individually marked, and three two-hour scan observations were made during either the morning or afternoon of each day during two summer, an autumn and a winter period. The locations of marked sheep were recorded, and a distance of 30 m taken as maximum between members of a group. A group of unmarked sheep from a different home range were also observed using similar methods. Cluster analysis was used to analyse individual home-range behaviour of individuals, and inter-cluster variability and compositional stability was tested.

Littlewood *et al.* (2006a) studied the effectiveness of moorland vegetation restoration in restoring the associated insect populations. This was carried out on the same sites and using a similar approach as reported in Littlewood (2006b) Vegetation was sampled at two spatial scales and soil samples taken for bulk density, pH, loss on ignition and moisture content. Hemiptera were sampled twice at each sample point by suction sampling, and Lepidoptera sampled by light trapping on over 40 nights, in each vegetation condition/restoration phase areas.

Littlewood *et al.* (2006b) studied the effectiveness of moorland vegetation restoration in restoring whole plant assemblages on a sample of eight sites, from the Peak District, England, to Perthshire in Scotland, using a correlative observational approach. Four sites were under restoration through grazing exclusion, and four had undergone herbicide and reseeding treatments, commencing 7 to 13 years before the survey. The starting point was generally species-poor acid grassland. Sampling at each site was stratified by vegetation condition and restoration phase (‘degraded’, ‘restored’ and ‘target’ long established dwarf shrub communities). The cover of all vascular plants, moss and lichens was assessed in six quadrats per vegetation area and soil samples taken for bulk density, pH, loss on ignition and moisture content. Ordination and modelling techniques were used to assess restoration success and identify significant factors.

Littlewood *et al.* (2006c) examined the effects of loss of heather, in which grazing was implicated, on the composition of the remainder of the vegetation, and the associated Hemipteran (true bug) assemblage. Six sites were selected from northern England to Aberdeenshire, all with areas of heather-dominated vegetation and grass-dominated areas where heather was known to have been recently lost. Vegetation composition and height was measured in six randomly placed quadrats in each vegetation type at all sites, and Hemiptera sampled by suction methods for set periods in each quadrat. Soil samples were also taken and bulk density, moisture content, pH and loss on ignition (LOI), a measure of organic matter, measured. All sites were sampled during two periods in one summer/autumn. Differences in vegetation and hemipteran populations were assessed by ANOVA and ordination methods, and stepwise selection and partitioning of variance was used to identify the main factors affecting plant and invertebrate compositional differences. Mean precipitation and temperature and latitude ware also included in the analysis.

Littlewood (2008) at Glen Finglas (see Dennis *et al*. 2008), sampled nocturnal moth abundance on four replicates of each treatment on six occasions over a four month period. Grazing treatments had been in place for five years. Moth groups were analysed by feeding preference, over-wintering strategy and conservation importance (BAP vs non-BAP species).

Littlewood *et al.* (2012) also at Glen Finglas (see Dennis *et al.* 2008), studied the effects of the grazing treatments on *Auchenorrhyncha* (order Hemiptera), previously shown to be affected by grazing intensity and vegetation quality. The plots were sampled in 2007 after several years of grazing treatment, using vacuum and sweep netting methods.

Marrs *et al.* (2004) considered sheep grazing, either year round or summer only at ESA (North Peak) and Countryside Stewardship (Yorkshire Dales) rates, in combination with burning and herbicide application, in controlling *Molinia* on white (*Molinia*-dominated) and grey (*Molinia-Calluna*) moors. However, due to winter removal, grazing ended up as summer only in both grazed treatments at both sites. The summer rates were around 0.87 ewes ha^{-1} plus followers in the North Peak ESA site and 1.5 ewes plus lambs ha^{-1} in the Yorkshire Dales Countryside Stewardship site.

Martin (2011) reported on monitoring montane moss-heath habitat response on the summit of Cross Fell, Cumbria, to reduced grazing pressure over an eight-year period. The moorland block in which it falls was entered into a Countryside Stewardship Agreement in 2003, under which sheep numbers were reduced to less than 1 sheep ha^{-1} (0.08 LU ha^{-1} yr^{-1}, assuming largely Swaledale sheep) with off-wintering and additional shepherding away from the summit plateau. The area was surveyed by random quadrats in autumn of four years over the period, although the number of quadrats varied between years. Cover was estimated and heights measured of key species, including *Racomitrium*, *Vaccinium*, *Carex bielowii* and lichens in each quadrat, along with bare ground and presence of droppings. Change over time was analysed by Analysis of Variance, with power analysis to test the effect of sample size.

Medina-Roldán *et al.* (2012) investigated the effects of medium-term grazing removal on soil carbon storage, at a site at Ingleborough NNR, Yorkshire Dales. The study took place after eight years of grazing removal on a large upland parcel (170 ha) and comparison made with a similar area, in terms of vegetation and topography, summer grazed by up to 4 sheep per ha and cattle. Turves were removed to 20 cm depth from sixteen sub-plots in each of six sample plots per treatment, five times over the course of just over one year. Turves were separated into different above and below ground organic fractions, and plants separated into functional groups. Spoil bulk density and total carbon and nitrogen were estimated for two sampling dates, and soil ammonium and nitrate was measured. Root cores were also taken in the field and water table sampled twice-weekly in each plot. Dissolved organic carbon was also measured. Grazing status and sampling date were considered as factors in the analysis.

Miller *et al.* (1999) investigated the effects of seasonal removal of grazing on alpine gentian (*Gentiana nivalis*) populations on Ben Lawers, Perthshire, Scotland. The effects on population density, growth, survival and seed production were considered. Eight pairs of 50 cm x 70 cm plots were surveyed annually for ten years, with one of each pair open to summer grazing (a mean annual rate of around 0.09 LU ha^{-1} yr^{-1}), and one protected during the grazing season. Quadrats were surveyed in summer and autumn, with number and heights of gentians recorded, and number of flowers, seed capsules, and seeds per capsule. The cover of bare ground was also recorded in the same small plots.

Miller *et al.* (2010) studied the effects of summer grazing removal on the alpine dwarf–shrub and herb community as a whole. Species cover was measured in each plot by point quadrat. Plants were grouped into functional groups for analysis.

Milligan *et al.* (2004) also investigated the effects of sheep grazing on *Molinia* growth in combination with cutting and herbicide or *Calluna* seeding. Sheep grazing was at ESA stocking rates (stated as 1.8 ewe's ha^{-1} yr^{-1}) with additional rabbit grazing compared with exclusion of both species.

Milne *et al.* (2002) undertook a three-year study of annual and seasonal biomass production from a range of upland heath and grassland types for England and Wales and investigated the effects of environmental variables on biomass production. The ITE land Classification system (Bunce *et al*. 1996) was used to identify randomized sample areas in six upland areas of England and Wales. For heather, areas of the different growth phases of pioneer, building, mature and degenerate were identified. In each 1 ha sample area, three seasonal exclosures were erected and biomass sampled by cutting quadrats to ground level in October. Cover measurements were made and biomass adjusted to 100% cover. For grasslands, biomass was measured at different parts of the growing season. As the most preferentially grazed grassland, *Agrostis-Festuca* grassland was cut to 4 cm at three points in the growing season, along with a final cut to ground level and these portions summed. Models were constructed using a number of soil and climate variables.

Mitchell *et al.* (2008) in a partially randomized factorial trial tested the efficacy of different grazing regimes and intervention techniques on the establishment of *Calluna vulgaris* in grass-dominated moorland swards. The two contrasting sites were the research farms at Pwllpeiran (*Nardus* dominated) and Redesdale (*Molinia*). At Pwllpeiran three blocks of three fields were randomly assigned to cattle, sheep or mixed grazing, and six 10 m x 10 m intervention plots established in each field. At Redesdale three 20 ha+ fields were grazed at either high sheep stocking rate plus cattle, low sheep and cattle or sheep only, with 18 intervention plots established. The Pwllpeiran stocking treatments were:

1) Cattle only - Welsh black heifers at 0.5 cows ha^{-1} in July and August (0.08 LU ha^{-1} yr^{-1});
2) Sheep only - Welsh mountain ewes at 1.5 ha^{-1} all year (0.12 LU ha^{-1} yr^{-1}); and

3) Mixed - Welsh mountain ewes at 1 ha^{-1} all year and Welsh Black heifers at 0.5 cows ha^{-1} in July and August (0.16 LU ha^{-1} yr^{-1}).

Redesdale stocking rates are given in Critchley *et al.* 2008 above.

Disturbance treatments were rotovation, trampling and an undisturbed control, assigned randomly to give two replicates per grazing paddock at Pwllpeiran, and six per paddock at Redesdale, but the same overall number for each grazing/disturbance combination. A further factor was introduced in seed addition to half of each plot, and an ungrazed exclosure set up perpendicular to this so each plot contained all combinations of seeded and unseeded, grazed and ungrazed. Heather establishment and cover of bare ground were measured in fixed quadrats, and seed bank was sampled before seed addition. The two sites were analysed separately to account for the differences in design, and a modelling approach used to identify the main factors affecting heather establishment. This paper reports findings from four years following treatment application.

In a continuation of the same trial at the Pwllpeiran site, Critchley *et al.* (in press) reported on the success of *Calluna* establishment eight years after initial treatment. A sample of plants in the grazed and ungrazed, seeded sub-plots were measured for height, shoot production and dry weight. Vegetation was measured in all subplots and in the surrounding paddock. Species cover and bare ground were recorded in fixed quadrats. Species composition had been previously measured in areas outside the paddocks to represent ‘target’ vegetation. A similar modelling approach was used to identify factors affecting heather establishment, and similarity indices of sub-plots to the target communities calculated for four and eight years after treatment.

Oom *et al.* (2008) in a replicated plot experiment studied the effects of heather defoliation and sheep behaviour on vegetation change, using three levels of summer sheep grazing. The treatments were 4, 3 and 2 sheep ha^{-1}, and were applied using one year old Scottish Blackface ewes randomly allocated to a pair of 1ha plots, one in each of two blocks. The plots were heather dominated, with varying amounts and distribution of grass. They had previously been used for the experiments described in Hester & Baillie (1998) and Hester *et al.* (1999), described above. Grazing took place from March to November in each of three years, with six animals grazed for different numbers of days to achieve the desired stocking rate. The annual stocking rates equate to 0.26 LU ha^{-1} yr^{-1}, 0.2 LU ha^{-1} yr^{-1}, 0.13 LU ha^{-1} yr^{-1}. Heather defoliation measured in October and April each year at the beginning and end of the grazing season, on transects perpendicular to grass/heather boundaries. Vegetation change was measured from maps made, using image classification techniques, from scanned aerial photographs taken at beginning (October 1998) and end (October 2001) of the experiment. The foraging and resting behaviour of each individually marked sheep was recorded from 25 daily binocular scans. The relationship between heather defoliation rate and change in cover, and change in grass cover at resting sites and across each plot were analysed.

Oom *et al.* (2010) investigated the effects of heterogeneity of grass: dwarf shrub mosaics and hypothesised that heterogeneity increases resistance to herbivory through greater dispersal of grazing impact. Three grazing levels of sheep (6, 4 and 3 sheep ha^{-1}) were applied in two replicated plots of each treatment, with mosaics of approximately 20% grass to 80% dwarf shrub. Plots were grazed over three years by groups of six sheep (Scottish blackface), grazed for varying lengths of time in each treatment over summer and winter to achieve the desired stocking rates heather defoliation was measured in October and April, from quadrats placed at fixed points on transects perpendicular to heather edges. Modelling and linear regression techniques were used to analyse the effect of grazing intensity on the change in defoliation with distance from the grass/heather interface.

Pakeman *et al.* (2003) in a replicated controlled trial in north-east Scotland studied the effects of four grazing treatments on degraded dry heath:

1) Summer high (1.86 sheep ha^{-1} yr^{-1});
2) Summer low (0.93 sheep ha^{-1} yr^{-1});
3) Winter high (1.64 sheep ha^{-1} yr^{-1}); and
4) Winter low (0.82 sheep ha^{-1} yr^{-1}).

There were additional control areas (prevailing agricultural grazing levels) and sheep and rabbit exclusion plots. Treatments were in place for 5 years. Measurements were made of *Calluna* and *Nardus* utilization and species frequency and structural components of *Calluna*.

Pakeman & Nolan (2009) analysed the results from ten similarly conducted experiments, in Scotland and north-east England. Three studies were previously published, including Hulme *et al.* (2002) and Pakeman *et al*. (2003), above. The studies covered a range of typical upland heath communities and a range of stocking rates from 0.4 to 2.1 sheep ha^{-1} yr^{-1} applied year round or in summer, with open hill comparisons, and in place for 5-6 years. Sheep breeds were largely Scottish blackface, with Cheviot and Swaledale at one and two sites respectively, giving a maximum treatment rate of 0.19 LU ha^{-1} yr^{-1} (other than one experiment with a maximum rate of 0.6 LU ha^{-1} yr^{-1}, set to achieve year round high heather utilisation rates). Heather utilisation and cover and/or frequency were measured at all sites.

Palmer *et al.* (2003) used a correlative survey approach to examine how the distributions of grass (preferred vegetation) within a heather-dominated (less-preferred vegetation) landscape influenced spatial variation in heather utilisation, by free-ranging red deer and sheep, at a range of spatial scales. Six grazing units were selected on the basis of deer density (low, medium and high) and within these a number of 0.25 km^2 sample areas were identified with either 1-8% grass or >12% grass by area. Heather heights were measured in quadrats along transects covering the range of grass patch sizes and dominant vegetation types and covering heather zones ‘distant’ from grass patches.

Poulton (2011) carried out an analysis of a large number of surveys of grazing pressure by Natural England and predecessor bodies. The surveys cover 141 sites throughout the English uplands with repeat visits to some resulting in 247 surveys and 26,000 vegetation quadrats. Surveys followed the same basic methodology and generally included measures of heather suppression, grazing index (proportion of shoots grazed) and graminoid heights, using a random sampling approach. The sites generally reflect high initial grazing pressure, with reduced stocking rates (Appendix 3) implemented before re-surveys. Within-site analysis of change was carried out for sites with repeat surveys, and a larger between sites analysis.

Pearce-Higgins & Grant (2002) used a correlative approach to examine the effects of grazing on skylark and meadow pipit density at a range of scales, using a number of number of habitat variables as surrogates for grazing intensity. A partially stratified random sample, based on heather cover, of 85 (2 km x 2 km) squares in northern England and southern Scotland were surveyed for the target species using a transect approach. Breeding densities were calculated. Vegetation height and structural measures were made and a number of indices (for example, tussockiness) derived.

Pearce-Higgins& Grant (2006) carried out a correlative study of the effects of structure and composition of moorland vegetation on breeding bird populations, using the same partially stratified moorland sample. A modelling approach was developed to identify the key vegetation and management variables influencing breeding bird density. The implications in terms of the likely grazing-related impacts of vegetation change on moorland bird populations are discussed.

Rawes (1983) reported on the long-term (14 years) stock removal on two plots of 0.1 ha on cotton-grass dominated blanket bog at Moor House NNR, North Pennines. The prevailing grazing rates were estimated at 0.25 and 0.5 sheep ha^{-1} in the two areas, grazed April- October. This equates to 0.01 and 0.02 LU ha^{-1} yr^{-1} based on the predominant Swaledale sheep. Vegetation change was measured from point quadrats on transects.

Rawes & Hobbs (1979) investigated the effects of long-term stock removal in thirteen plots, of between 0.1 and 3.4 ha in area, on blanket bog vegetation on Moor House NNR, North Pennines. At the time of the study, grazing had been excluded for between 18 and 26 years, as exclosures were established at different times. The plots were likely to have been located subjectively, but to cover some of the variation in the blanket bog community. Within each plot change in vegetation composition and structure from point quadrat measurements, and spatial distribution from small-scale mapping was measured over time, and used to analyse change. Comparison areas outside of the plots were also assessed. Monitoring had taken place at the establishment of the most recent plots, and seven years later, with the most recent assessment eighteen years after establishment. A second experiment includes work relating to burning rotations. This was not presented in detail but included combinations of burning with heavy (0.34 LU ha^{-1} yr^{-1}) and light (0.04 LU ha^{-1} yr^{-1}) sheep grazing, assessed on small plots over 7 years. Comparisons were made with background levels on the grazing unit of 0.01 LU ha^{-1} yr^{-1}.

Roberts (2002, 2003, 2010) discusses the effects of large-scale livestock removal following foot and mouth disease (FMD) on botanically rich habitats and populations of rare and uncommon montane plants in the Cross Fell range, Cumbria. The findings are based on extensive semi-surveys by experienced amateur botanical recorders.

Ross (2000) investigated the effect of summer sheep grazing in controlling *Molinia* on heather stands burned at different ages. Two grazing rates were imposed, measured by herbage utilization at 33% and 66% of *Molinia* leaf production removed.

Rushton *et al.* (1996) examined the effects of grazing management on moorland vegetation at the plot field and farm scale on two experimental hill farms. At Pwllpeiran in mid-Wales three grazing treatments were applied to unreplicated plots: a standard ESA rate, given as 1.25 ewes ha^{-1}; ESA rate -30%, given as 0.83 ewes ha $^{-1}$; and no grazing. Plots were grazed April-October by Welsh Mountain sheep (these rates equate to 0.1 LU ha^{-1} and 0.07 LU ha^{-1}, although it is not clear if this is the rate for the grazing period, or an annual average). A field-scale study looked at two similar grazing treatments on larger areas of *Nardus* grassland and *Calluna-Vaccinium* heath. A farm-scale experiment at Redesdale research farm, Northumberland, applied a high (2.1 ewe's ha^{-1}) stocking rate and a 30% reduction (1.48 ewes ha^{-1}) to enclosures of about 60 ha each with similar grassland and heathland communities. The quoted rates equate to 0.21 LU ha^{-1} and 0.15 LU ha^{-1} as sheep are largely Scottish blackface. Again it is unclear if these rates are annual averages, or for the grazing period. Vegetation was monitored in fixed quadrats in all studies. A Markov modelling approach was used to predict longer term vegetation change at all scales.

Sibbald *et al.* (2008) using the same experimental plots as Oom *et al.* (2010) examined the interaction of social behaviour and vegetation pattern on distribution of sheep, and their utilization of vegetation patches. Six groups of six randomly allocated yearlings Scottish blackface each grazed one plot for a two-week period (0.6 LU ha^{-1} over the grazing period). Animals were individually marked for distance identification. Twenty-five telescope scans were made during daylight hours on each of 11 days. Type of behaviour displayed by each individual during each scan period was recorded. The observed versus expected locations based on patch size was analysed.

Smith *et al.* (2003) studied the effects of grazing removal in small plots at Butterburn Flow, a raised mire in Kielder Forest, Northumberland. Five pairs of 20x20 m plots were established in a stratified random manner, to cover the central and peripheral zones of the mire. One plot of each pair was fenced to exclude sheep grazing. The average stocking rate on the moor was around 0.05 LU ha^{-1} yr^{-1}, although it was stated that the centre of the mire was largely avoided. Vegetation, including species frequency, was surveyed in random quadrats at baseline and a further twice over fifteen years. Ordination techniques were used to compare the quadrat data with a wider mire dataset and track changes over time. The prevailing level of grazing on the mire is not specified.

Uff (2011; and previous reports) reports the results of heather condition monitoring by the National Trust on the Long Mynd, Shropshire, over a period of sheep reductions. The common is largely dry acid grassland and heathland, with flushes. It was grazed at a rate of up to 5 ewes ha^{-1} in the mid-1990s, which was reduced in 1995 to 3.5 ewes ha^{-1} in summer and 2.5 ha^{-1} in winter through cross compliance measures, and further reduced in 1999 to 1.5 ewes ha^{-1} in summer and 0.75 ewes ha^{-1} in winter under ESA prescriptions and has since remained relatively stable. The annual average rate is now around 0.1 LU ha^{-1} yr^{-1}. Heather condition has been monitored since 1998 in 37 fixed plots; measures include cover, condition, age-class and grazing index from shoots. Frequency of other plant species is also recorded, and sheep numbers are estimated from a fixed walking route. Analysis has largely consisted of trend graphs of means of variables measured.

Vandenberghe *et al.* (2009) studied foraging site selection in meadow pipits in two of the grazing treatments at Glen Finglas (see Dennis *et al.* 2008), intensive sheep (c. 0.17 LU ha^{-1} yr^{-1}) and low intensity mixed grazing (c. 0.08 LU ha^{-1} yr^{-1}), five years after treatments started. The other treatments did not have sufficient nests for replication. Nests with chicks aged between 5 and 8 days were selected, to reduce temporal variability in associated adult foraging and provisioning behaviour. Study squares were placed at foraging points, where birds were observed to fly from with food, and paired with random squares, as with Douglas *et al.* (2008). Invertebrate and vegetation composition and structure measurements were made in each square and comparisons made between square types and grazing treatments.

Van der Wal *et al.* (2003) examined the interaction of nitrogen application and grazing on the balance of *Racomitrium* moss and grasses in a high level moss-heath in the Scottish Highlands. Low (10 kg ha^{-1} yr^{-1}) and high (40 kg ha^{-1} yr^{-1}) N rates and a distilled water control were applied in 10 replicate blocks. Sheep habitat usage was measured by dung counts in systematic count plots, and vegetation cover assessed by pin frame, along a gradient of grazing resulting from the sheltering effects of a snow fence (also reported in Welch, 2005). Small grazing exclusion cages were also established, to measure *Racomitrium* shoot growth in the absence of grazing.

Ward *et al.* (2007) studied the long-term consequences of regular disturbance from controlled burning and grazing, on their own and in combination, on vegetation composition, C stocks, dissolved organic carbon (DOC) carbon dioxide (CO_2) and methane (CH_4) fluxes, on blanket bog on the Hard Hill plots at Moor House NNR (see Garnett, 2000). This used the 10-year burn rotation and unburned treatments at the sites. Peat cores were taken to 1m, and gas samples and soil water samples taken monthly over an 18-month period.

Webb (2012) reported the effects of significant reduction in grazing from annual average of c. 0.14 LU ha^{-1} to 0.04 LU ha^{-1}, including off-wintering on Glenridding Common. The common is part of Helvellyn and Fairfield SSSI, Lake District, Cumbria, extending to the summit of Helvellyn. stock reductions had been in place for around 9 years through agri-environment schemes. Findings are based on repeat casual observations, particularly of locations of important and sensitive plant communities.

Welch, (1984 a, b) carried out a large-scale correlative study of the effects of grazing of livestock and wild herbivores on heather moorland in north-east Scotland. Thirty-two sites were selected over a 5000 km^2 area, covering a range of altitude and avoiding blanket bog, but predominantly *Calluna* dominated with a wide range of associated species. Each site consisted of 0.4-2 ha of relatively homogenous vegetation, but with varying management regimes. Four types of site were identified: range restricted, i.e. less than 50ha, or unrestricted; and with and without access to improved grass. Dung was counted from fixed plots at three weekly intervals and separated into different types of grazing animal. Grazing utilisation of dwarf shrub species, graminoids and other key species such as *Alchemilla alpina* was measured four times per year. Monitoring continued over at least four years.

Welch (1985) in the same study assessed the germination of plants on cattle dung.

Welch (1998) studied the effects of summer and winter sheep grazing in a replicated paddock study at a bilberry *Vaccinium myrtillus* dominated and a heather-bilberry site in the Derbyshire Peak District. The author describes the sites as H18 (*Vaccinium myrtillus – Deschampsia flexuosa*) heath, but at lower altitude than typical for this community and transitional to H9b (*Cladonia* sub-community of *Calluna vulgaris – D flexuosa* heath). The grazing treatments were implemented by opening and closing paddocks to the prevailing grazing of the surrounding moorland, with summer and winter periods being slightly different length in some years to equalise occupancy, as assessed by dung counts. Species frequency were measured annually using systematic point quadrat sampling, and heather and bilberry measured four times per year in fixed areas.

Welch *et al.* (2005) using a correlative approach, studied the effects of increased sheep grazing due to the sheltering effects of a snow fence on montane moss-heath in the Scottish Highlands (also reported in Van der Wal *et al.* 2003), over a twelve year period. The sheep fence caused a gradient in grazing with highest levels close to the fence, with occupancy assessed by dung counts. Species cover, particularly *Racomitrium* moss and stiff sedge (*Carex bigelowii*) was assessed on transects perpendicular to the fence.

Welch *et al.* (2006) investigated the effects of reducing red deer *Cervus elaphus* numbers within extensive sites using a correlative approach, to record how long it took for suppressed heather to recover. The two study areas were in the eastern Cairngorms, Scotland. Habitats were largely wet heath and grassland, with no controlled burning in place. Deer numbers have been reduced by a similar magnitude in both areas over time, but winter feeding took place in one of the areas. Both areas were sampled systematically in each of 10 years, with deer and rabbit dung measured in plots, and heather height, cover and utilization measured in April. Deer counts were also made monthly from October to April. Models were built to assess deer occupancy against environmental variables.

Welch & Rawes (1964) studied the effects of grazing removal on three high level grassland plots (40 m x 40 m) at Moor House NNR in the North Pennines after seven years. Herbage biomass was sampled in addition to species composition form point quadrats. The moorland is summer grazed largely by Swaledale sheep, with annual average grazing rates estimated as 0.1-0.2 LU ha^{-1} yr^{-1} based on summer counts. The same sites were used in Rawes (1983).

Welch & Rawes (1966) carried out an observational comparative study on three areas of blanket bog vegetation, around the headwaters of the River Tees, again on Moor house NNR. The three sites were in different grazing units separated by fences, and had different grazing histories, varying in grazing pressure and heather cover. Grazing animal counts were made over a 14 month period and quadrat estimates of vegetation cover made along with sampling of heather biomass. Limited quantitative or correlative analysis was carried out.

Williams *et al.* (2011) investigated ranging behaviour of hill sheep through the use of GPS collars. The study site was an area of 217 ha in Co Mayo, Ireland, on peat with blanket bog, wet heath and patches of acid grassland. Four Scottish blackface ewes were tracked over nine sampling periods in different seasons over a two-year period. The same sheep were used as far as possible, but there was some substitution due to poor body condition pre-lambing, or twin-bearing. The overall average stocking rate during the period was 0.08 LU ha^{-1} yr^{-1}. Ewe locations were recorded at 10-minute intervals and data retrieved after 5 weeks for each period.

Worrall *et al.* (2007) in the partially randomized, replicated plots at Hard Hill, Moor House NNR (see Clay *et al.* 2009) examine the consequences of different burn regimes, 10 and 20-year rotation and no burning, and absence or presence of grazing on the hydrology and soil water quality of an upland peat. The stocking rate on the moorland grazing unit was 0.03-0.05 LU ha^{-1} yr^{-1}, but estimates for the grazed plots are lower. Water table depth was measured and soil water samples obtained from three dipwells per plot, placed at random. Samples were analysed for pH, conductivity, dissolved organic carbon (DOC) concentration and absorbance (an indirect measure of DOC). Sampling took place fortnightly over the summer months in one year (April- end September) giving 16 sampling visits, towards the end of the 10-year burning cycle. The results were analysed factorially on raw and normalized data. Normalization involved calculating the difference of the mean results from each treatment against the mean for the grazed, unburned treatments, taken to be the control.

Worrall *et al.* (2008) also assessed water quality using the sampling system in the above study, with sampling extended over a complete year. Water samples were analysed for Al, Fe, Ca, Mg, K, Na, Si, fluoride, chloride, bromide, nitrate, phosphate and sulphate. Cation and anion measurements were made by spectroscopic and chromatographic analytical techniques respectively, and data analysis involved similar methods to Worrall *et al.* (2007).