CEE review 05-009

DOES SHEEP-GRAZING DEGRADE UNIMPROVED NEUTRAL GRASSLANDS MANAGED AS PASTURE IN LOWLAND BRITAIN?

Systematic Review

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Protocol published on website: April 2005 - Review published on website: 26 May 2006

Cite as: Stewart, G.B. & Pullin, A.S. 2006. Does sheep-grazing degrade unimproved neutral grasslands managed as pasture in lowland Britain? CEE review 05-009 (SR15). Collaboration for Environmental Evidence: www.environmentalevidence.org/SR15.html.

SYSTEMATIC REVIEW SUMMARY

Background
Grazing is a common management intervention for maintaining conservation value of lowland grassland throughout Great Britain. Cessation of livestock grazing on lowland grassland has reduced the conservation value of many sites but over-grazing can also be damaging. There is also concern that grazing by sheep reduces the conservation value of pastures more than grazing by cattle. As heavy sheep grazing is becoming more prevalent, empirical evidence regarding its impact is urgently required to inform decision-making.

Objective
To assess the impact of sheep grazing on *Cynosurus cristatus-Centaurea nigra* (MG5) 'old meadow' pasture compared to cattle grazing, horse grazing or no management.

Search strategy
Electronic searching of ISI Web of Knowledge, Science Direct, Directory of Open Access Journals (DOAJ), Copac, Scirus, Scopus, Index to Theses Online (1970-present), Digital Dissertations Online, Agricola, Europa, English Nature's "Wildlink", JSTOR, BIOSIS via EDINA, SIGLE via ARC2WebSPIRS. Publication searches of Agricultural Development and Advisory Service, Countryside Council for Wales, Department of Agriculture and Rural Development, Department of Environment, Food and Rural Affairs, English Nature, Joint Nature Conservation Committee, National Trust, Royal Society for the Protection of Birds, Scottish Natural Heritage. World Wide Web searches of the meta-search engines Dogpile, Alltheweb and Google Scholar. Hand-searches of bibliographies of accepted articles. Personal contact with leading researchers.

Selection criteria
Any studies comparing the impact of sheep grazing with cattle, horses or no management on MG5 pasture in Great Britain or Ireland. Information from other grassland vegetation with floristic affinities in NW Europe was also considered for inclusion.

Main results
Forty two studies fulfilled the inclusion criteria. Approximately, half the studies (22) were reviews, of which 12 considered only single species. Experimental and management methodologies were too diverse for meta-analysis. The results of these studies are summarised in the text.

Grazing impacts on plants are species specific and vary with stock type, and intensity of grazing. The available data do not provide clear unequivocal evidence regarding the impact of sheep grazing on pasture, but suggest that intermediate levels of grazing are most appropriate for conservation objectives with regard to plant species.

Experimental work often fails to report management activities adequately. Even where specific stock details are available, comparisons and starting points are too varied for meaningful synthesis. Generic grazing experiments agree that land use history has an important influence on species composition but are too context specific and diverse in management and outcome for general conclusions to be made.

Only one article (Roberts 1928) provides a direct comparison of sheep and cattle-grazed MG5 pasture. Plant species richness, forb biomass and diversity were lower in sheep grazed pasture. A comparison of sheep and cattle grazing on artificially restored MG5 reports a similar pattern of reduced plant diversity and forb cover under sheep grazing (Warren et al. 2002). Further work on MG5 compares the impact of horses and cattle (Gibson 1996, 1997) cautioning that species of grazer has a minor impact compared to intensity of grazing. Horses do damage MG5 sites but only at high grazing intensities, and cattle also damage sites at high grazing intensity. There are subtle variations in like-for-like impact, and these are valuable in themselves. Degradation at high grazing intensities is manifest as a reduction in floristic species richness and loss of important indicator species.

There is even less information available on grazing impacts on taxa other than vascular plants. Reviews suggest that intermediate grazing levels maximise biodiversity benefit across taxa (birds, insects and soil biotic diversity). However experimental work indicates that this may not always be the case.

Analyses of raw data from welsh MG5 grassland demonstrate that stock type and vegetation height significantly impact on plant community composition, species richness and forb abundance. However, mean forb abundance for horse, cattle and sheep-grazed sites are 11.7, 10.7 and 10.5 respectively. Thus the differences between stock types are not ecologically significant. Maximising forb abundance and species richness is achieved by maintaining sward heights at 0-10 cm for cattle and horses, although maximum forb abundance is found at sward heights >10cm for sheep, perhaps suggesting that MG5 grassland cannot support sheep grazing at the same intensity as cattle and horses if forb abundance is to be maintained.

Conclusions

Implications for conservation

Available evidence suggests that conservation managers considering grazing on MG5 sites should primarily be concerned with grazing intensity. Grazing at low intensities increases sward height and forb diversity but overall plant species richness is limited as bryophyte abundance declines.

Choice of stock type appears to be less critical than grazing intensity but there is some evidence that sheep grazing can result in lower forb diversity than cattle grazing at high stocking rates. There is no empirical evidence regarding the impact of different breeds on MG5 grassland, but we assume the impact of breed is negligible given that differences between species of stock are not large.

Further evidence regarding grazing intensity-stock type interactions is noticeably lacking, precluding prediction regarding stock type impacts at given stocking intensities. Lack of detailed knowledge of land-use history is a major impediment and there is little information regarding taxa other than vascular plants.

Managers must balance changes in bryophyte abundance, forb diversity and plant species richness to achieve tradeoffs appropriate to their conservation objectives. As different taxa have different (and often unknown) management requirements, the poor evidence-base necessitates flexible site-based adaptive management and rigorous monitoring where grazing of important MG5 pastures is undertaken.

Implications for further research

Robust empirical evidence for the effectiveness of low intensity grazing to achieve conservation objectives on MG5 pasture is lacking. High quality comparative work comparing cattle and horse grazing is available together with lower quality information regarding sheep. A comparative dataset of 1600 grassland samples is also available. This work suggests that heavy grazing reduces plant and forb diversity and that grazing by sheep reduces diversity more than grazing by cattle. However, considerable uncertainty surrounds these results that are derived from comparisons and one short-term factorial experiment on restored MG5. More robust long-term experimentation and monitoring are required to develop the necessary evidence-base. Many important questions remain unanswered. In particular, more information is required regarding stock type-grazing intensity interactions and very little is known about grazing impacts beyond local variation in plant species richness.

1. BACKGROUND

Grazing is a common management intervention for maintaining conservation value of lowland grassland throughout Great Britain (Crofts & Jefferson 1999, UK BAP 2005). Cessation of livestock grazing on lowland grassland has reduced the conservation value of many sites (Preston *et al.* 2002) but inappropriate grazing intensities or stock types can also be damaging (Crofts & Jefferson 1999, UK BAP 2005). In the Countryside Council for Wales (CCW) rapid assessment exercise, grazing was the first listed management factor affecting habitat condition at 63% of lowland grassland features in unfavourable condition.

Unimproved neutral grasslands (specifically MG5 *Cynosurus cristatus - Centaurea nigra* grasslands) have high nature conservation value and are often grazed by sheep (Crofts & Jefferson 1999). Casework concerns from local CCW staff have focused on sites managed as pasture, where reductions in forb frequency and cover have been associated with summer sheep grazing. The Tir Gofal management prescription for unimproved grassland addresses these concerns by providing financial incentives to graze with cattle at a minimum stocking intensity of 0.1 Livestock units/ha. Further payment is made if the cattle are Welsh blacks (Tir Gofal 1999). However, much of the evidence concerning the impact of sheep grazing on neutral grassland is anecdotal. The impact of sheep grazing on the floristic composition of neutral grassland must be compared to management with other stock types in order to develop and refine grazing practices to achieve conservation objectives.

A large number of variables add complexity to this issue. Grazing intensity, period, duration, breed of sheep and initial floristic composition have been identified by CCW as potential effect modifiers of decreasing importance. Grazing intensity has a large impact on biomass offtake and selectivity which are both important determinants of floristic composition (Armstrong & Milne 1995, Milne *et al.* 1998). The nutritional characteristics of swards vary seasonally thus grazing period also effects selectivity, whilst the duration of grazing relates to the magnitude of changes due to grazing intensity and period (Armstrong & Milne 1995, Milne *et al.* 1998). There are around 50 native sheep breeds in Britain (Crofts & Jefferson 1999). Selectivity, biomass offtake, and flock behaviour vary with sheep breed and influence the outcome of grazing interventions (Armstrong & Milne 1995, Milne *et al.* 1998). The initial floristic composition represents the baseline from which changes occur, and can have a strong influence on any subsequent successional modification. Likewise, floristic responses to grazing are dependent upon time. Short-term studies can miss potentially important vegetation responses (Bullock *et al*., 2001). The impact of sheep grazing on the floristic composition of neutral grassland cannot be ascertained without concurrent investigation of the impact of these factors.

An explicit systematic review methodology was used to retrieve data pertaining to the impact of sheep grazing on the floristic composition of neutral lowland pastures. The review limited bias through the use of comprehensive searching, specific inclusion criteria and formal assessment of the quality and reliability of the studies retrieved. Subsequent data synthesis summarises empirical evidence guiding the formulation of appropriate evidence-based management guidelines and highlights gaps in research evidence. The review should be of use to UK conservation agency ecologists and regional staff, agri-environment scheme developers and officers, non-governmental organisation management advisers and site managers informing decisions over national management guidelines and management of individual sites at a local level.

2. OBJECTIVES

2.1 Primary objective

The primary objective was to systematically collate and synthesise published and unpublished evidence in order to address the following question:

"Does sheep-grazing degrade unimproved neutral MG5 grasslands managed as pasture?"

2.2 Secondary objective

A secondary objective was to determine what influence grazing intensity, period, duration, breed of sheep, initial floristic composition and follow up period have on the impact of grazing?

3. METHODS

3.1 Search strategy

Electronic database and internet searches
The following electronic databases were searched using the terms: grass* and graz*, grass* and sheep, grass* and manage*, grass* and conservation, meadow* and graz*,pasture* and graz*.

1. ISI Web of Knowledge
2. Science Direct
3. Directory of Open Access Journals (DOAJ)
4. Copac
5. Scirus
6. Scopus
7. Index to Theses Online (1970-present)
8. Digital Dissertations Online
9. Agricola
10. Europa
11. English Nature's "Wildlink"
12. JSTOR
13. BIOSIS via EDINA
14. SIGLE via ARC2WebSPIRS

Publication searches were undertaken on conservation and statutory organisation websites (Agricultural Development and Advisory Service, CCW, Department of Agriculture and Rural Development, Department of Environment, Food and Rural Affairs, English Nature, Joint Nature Conservation Committee, National Trust, Royal Society for the Protection of Birds, Scottish Natural Heritage) and using the meta-search engines Dogpile, Alltheweb and Google Scholar. The first 100 word document or PDF hits from each data source were examined for appropriate data. In addition bibliographies of articles viewed at full text were searched.

3.2 Study inclusion criteria

- **Relevant subjects:** Unimproved neutral grasslands managed as pasture (Communities with affinity to NVC MG5 *Cynosurus cristatus - Centaurea nigra* grasslands).
- **Type of Intervention:** grazing by domestic stock (cattle, horses, sheep).
- **Types of Outcome:** The primary outcome is change in floristic composition. However studies will not be rejected on the basis of outcome and outcomes other than change in floristic composition will be catalogued. An *a priori* definition of magnitude was required to define an ecologically meaningful adverse outcome. Adverse outcomes were defined by CCW as: reduction of forb cover by 10 % or more or a reduction of forb species richness of 10 % or more of the following 'desirable' species: *Agrimonia eupatoria, Alchemilla* spp., *Anemone nemorosa, Centaurea nigra, Filipendula vulgaris, Galium verum, Genista tinctoria, Lathyrus linifolius, Leontodon hispidus, L. saxatilis, Lotus corniculatus, Pimpinella saxifraga, Polygala* spp., *Potentilla erecta, Primula veris, Sanguisorba minor, S. officinalis, Serratula tinctoria, Silaum silaus, Stachys officinalis, Succisa pratensis*

3.3 Relevance assessment

A single reviewer assessed relevance by excluding articles with obviously irrelevant titles. Subsequently, the abstracts of the remaining studies were examined with regard to possible relevance. Where there was insufficient information to make a decision regarding study inclusion when viewing titles and abstracts, then relevance to the next stage of the review process was assumed. A second reviewer independently assessed a random subset of the articles to demonstrate the repeatability of the method.

3.4 Data synthesis

Qualitative synthesis
Information regarding the subject, intervention, outcome and methodology was extracted from the studies and collated in tables.

Statistical analyses of raw data
Raw data from welsh MG5 grassland (Phase II habitat data) was made available by CCW. Amalgamation of thirteen grassland datasets across Wales provided 1600 samples of MG5 grassland with associated management information. We examined the general structure of the phase II data with Detrended Correspondence Analysis (DCA) (Hill 1974) using Canoco version 4.5 (ter Braak & Smilauer 2002). No transformation or down-weighting was undertaken to avoid introducing *post hoc* bias. Gradient lengths of the ordination axes (of < 3) suggested that Redundancy Analysis RDA was the appropriate means of analysing the relationships between management variables and grassland assemblages (ter Braak & Smilauer, 2002). Prior to the RDA all environmental and landscape variables were independently examined with a Monte-Carlo randomization test (Manly, 1994) with 999 permutations (Warnaffe and

Dufrene 2004). RDA was used to examine the relationship between environmental factors and grassland community composition. Variance partitioning was used to separate the effects of stock type and vegetation height (Leps and Smilauer 2003). Two-way ANOVA was used to examine the response of forb abundance and species richness to stock type and vegetation height (Underwood 1997), on factors with homogeneous variance (Levene 1960). Post ANOVA comparison tests were performed using the Bonferroni method to assess the significance of differences between sheep grazing and other stock types (cattle, horses, cattle and sheep) at sward heights <10cm (Neter *et al.* 1990).

4. RESULTS

4.1 Review statistics

Review summary statistics and repeatability

Searching electronic databases retrieved 13060 references (excluding duplicates) with further references identified from bibliographies, web and library searches. Of these, 1628 had relevant titles (agreement between independent reviewers being substantial, K=0.61). 115 references were judged relevant upon reading abstracts (agreement between independent reviewers initially fair (K = 0.35) but substantial once general grassland references were excluded, K= 0.79).

Of the 115 references, 42 studies fulfilled the inclusion criteria. Approximately, half the studies (22) were reviews, of which 12 considered only single species. Experimental and management methodologies were too diverse for meta-analysis. The results of these studies are summarised in the text below and in tables (Appendix 1). CCW provided additional relevant raw data for analysis, when asked to provide the data they held regarding MG5 floristic composition in Wales.

4.2 Review outcome

Available evidence from existing review articles suggest that grazing has variable impacts. Grazing impacts are plant species specific and vary with stock type, and intensity of grazing. They do not provide clear unequivocal evidence regarding the impact of sheep grazing on pasture, but suggest that intermediate levels of grazing are most appropriate for plant conservation objectives (appendix one). Where grazing levels are very low or where sites are left ungrazed for a long period of time, succession proceeds to floristically impoverished and forb-poor grassland dominated by *Arrhenatherum elatioris* (Rodwell 1992). Conversely, where grazing levels are very high, sites become dominated by a limited range of competitive species at the expense of stress-tolerators resulting in decreased species richness (Grime *et al.* 1992).

Reviews of single species suggest that forbs increase in abundance (4), remain stable (1) or decline (1) in response to grazing, whereas graminoids increase in abundance (2), remain stable (1) or decline (2). Given the species specific nature of plant responses and the large number of confounding variables this information is of limited predictive value.

Only one article (Roberts 1928) provides a direct comparison of sheep and cattle grazed pasture with strong affinity to MG5. Both pastures were similarly managed for at least 20 years. Six years prior to the study, one pasture carried a "heavy stock of bullocks" in summer, whilst the other was stocked by sheep at 2.07LSU/ha (100 sheep to 18 acres). This probably equates to 1.04LSU/ha/yr which is a high annual stocking rate for species rich MG5 grassland (Jefferson *Pers comm.*) with rates equating to favourable condition in lowland grassland cited as 0.5 - 0.75LSU/ha/yr (Kirkham *et al.* 2003) (Tir Gofal prescription 0.75LSU/ha/yr). Thus a comparison of stock types at high grazing intensities suggests that "the harmful effect of exclusive sheep grazing is very pronounced." Vascular plant species richness declined with the loss of *Poa pratensis* and *Festuca pratensis*, whilst *Dactylis glomerata* declined to near vanishing point. There was also a reduction in forb biomass and diversity, although *Ranunculus bulbosus* and *Cerastium fontanum* persist. Both these forbs are dependent upon the debilitation of potential dominants for survival and are therefore frequent in grazed habitats although *Cerastium fontanum* is eaten by cattle and appears sensitive to trampling (Grime *et al.* 1992).

A comparison of sheep and cattle grazing on artificially restored MG5 reports a similar pattern of reduced plant diversity and forb cover under sheep grazing (Warren et al. 2002). Plots grazed by cattle were found to contain more than twice as many sown MG5 species as did plots grazed by sheep. Cattle-grazed treatment (sown plots) experienced no decline in the number of sown species persisting. In this case, community change occurred as a result of an increase in cover of two non-sown species, *Trifolium. repens* and *Ranunculus. repens*. The vegetation that developed in the sheep-grazed plots was species-poor, it had <1% cover of forbs by the sixth year and was dominated by the sown grasses possibly due to selective grazing. The biennials *Cirsium vulgare* and *Senecio jacobaea* which were generally tall and unpalatable thrived under grazed-only treatments but did less well when prevented from flowering by cutting. In contrast, the low-growing perennial forbs *Ranunculus repens* and *Trifolium repens* became more abundant when the vegetation was cut, but not under conditions of extreme defoliation associated with sheep grazing.

Further work on MG5 compares the impact of horses and cattle (Gibson 1996, 1997) cautioning that species of grazer has a minor impact compared to intensity of grazing. Horses do damage MG5 sites but only at high grazing intensities, and cattle also damage sites at high grazing intensity. There are subtle variations in like-for-like impact, and these are valuable in themselves. Degradation at high grazing intensities is manifest as a reduction in floristic species richness and loss of important indicator species.

Subject experts identified a further review article, which while not directly relevant, provided peripheral information. Tallowin (2005) found that maintaining sward heights at >8cm allowed forb flower heads to develop on neutral grassland. However, plant and insect diversity declined across all cattle grazed treatments in this experiment reflecting pre-experimental management of the site as a hay-meadow.

4.3 Statistical analyses of raw data from welsh MG5 grassland

DCA gradient lengths (range of sample scores divided by average within-species standard deviation) are <4 (Table 1) suggesting that the grassland species responses are not unimodal indicating that RDA is the appropriate method of direct gradient analysis. Cumulative variance is low (Table 1) suggesting considerable variation between samples in terms of species presence or absence.

Table 1. DCA summary statistics

Axes	1	2	3	4
Eigenvalue	0.183	0.149	0.115	0.102
Length of gradient	2.595	2.905	2.512	2.404
Cumulative variance %	2.3	4.1	5.5	6.8

Monte Carlo tests demonstrate that all environmental variables are significantly related to community composition (Table 2). A total of 10% of the species and 77.6% of the species-environment variation are accounted for by the four axes of the RDA using these variables. The RDA analyses have small variance inflation factors and CANOCO detected no colinearity between variables, although splitting stock type from a single factor with 24 levels to 24 binary factors does result in high variance inflation factors for cattle, cattle and sheep, and horses and sheep.

Table 2 Environmental variables used in the redundancy analyses. F and P values were generated using Monte Carlo Permutation tests, using 999 permutations.

Variable	Properties	F	P
Bryophyte abundance	Continuous- interpretative summary measure	44.05	0.001
Forb abundance	Continuous- primary outcome measure	83.93	0.001
Forb frequency	Continuous- primary outcome measure	13.24	0.001
Management	Ordinal (2 factors)-confounding variable	2.02	0.002
Grazing stock type	Ordinal (24 factors modeled as 24 binary variables in subsequent RDA)- intervention measure	6.75	0.001
Vegetation height	Continuous-interpretative summary measure	11.93	0.001

The RDA biplot (Figure 1) shows associations between the relative abundance and frequency of forbs such *Centurea nigra, Succisa pratensis* and *Leontodon hispidus* and grazing stock type. There is also a relationship between the abundance of bryophytes such as *Rhytideadelphus squarrosus, Calliergon cuspidatum* and *Pseudoscelropodium purum* and vegetation height. The correlations between grazing stock type and forb abundance are shown together with mean forb abundance and sample size for cross reference (Table 3). Small samples sizes hinder interpretation of stock type influence except for horses, cattle, sheep and combination stocking of cattle and sheep. Mean forb abundance decreases through the series horses, cattle, sheep, cattle and sheep whilst both cattle and sheep presence is negatively correlated with forb abundance (Table 3).

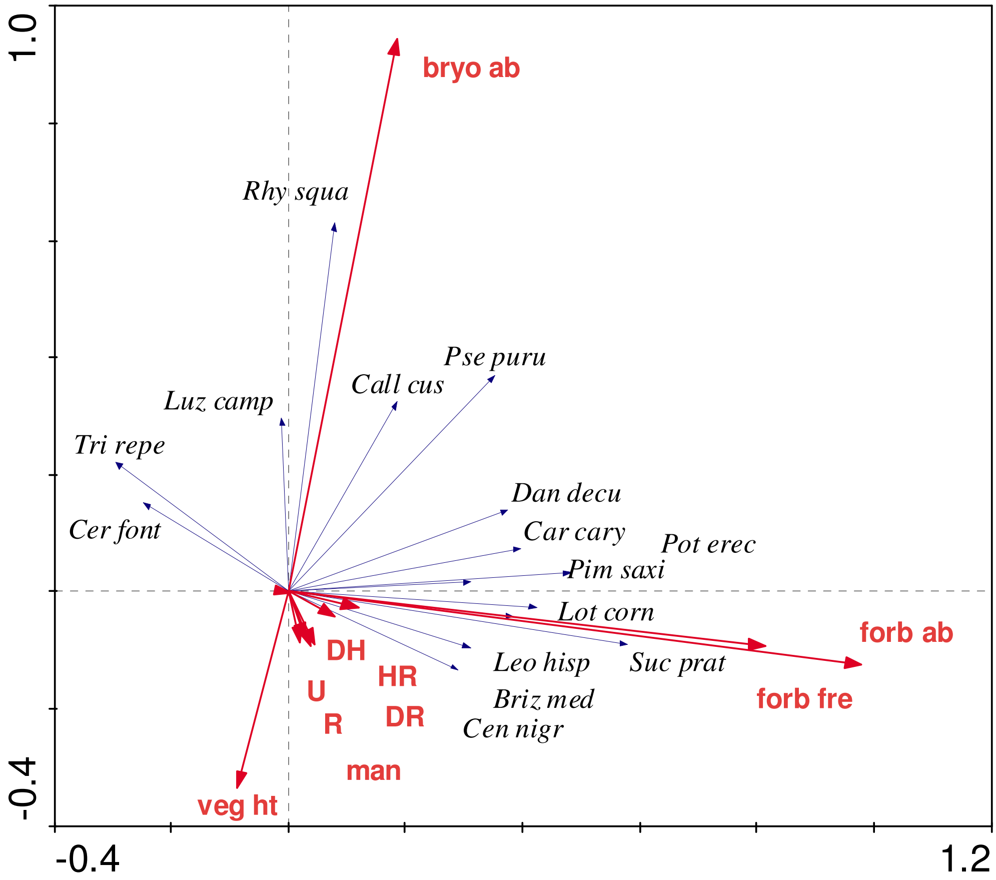

Figure 1. Axis 1 by Axis 2 RDA biplot of grassland composition in relation to explanatory variables. Abbreviations are: forb ab (forb abundance), forb fre (forb frequency), man (management), DH (donkeys and horses), HR (horses and rabbits), U (ungrazed), DR (donkeys and rabbits), R (rabbits), veg ht (vegetation height), bryo ab (bryophyte abundance).Variables and species explaining less variation were omitted from the biplot for clarity.

Table 3. Relationships between forb abundance and grazing stock type

Grazing stock type	RDA correlation with forb abundance	Mean forb abundance	n
Donkeys, Horses	0.078	27.00	1
Rabbits	0.090	16.90	10
ungrazed	0.058	16.40	5
Goats, Horses	0.024	16.00	1
Donkeys, Rabbits	0.037	14.17	6
Horses, Rabbits	0.078	14.00	30
Horses, Rabbits, Sheep	0.026	13.75	4
Cattle, Horses	0.083	13.40	53
Goats, Sheep	0.013	12.67	3
Horses	0.073	**11.73**	425
Cattle, Sheep	0.008	**11.25**	143
Horses, Sheep	-0.012	10.78	49
Cattle	**-0.067**	**10.65**	560
Sheep	**-0.045**	**10.48**	185

Rabbits, Sheep	-0.028	9.54	13
Cattle, Rabbits	-0.056	9.31	39
Goats	-0.010	9.00	1
Donkeys, Goats, Horses	-0.010	9.00	1
Cattle, Goats	-0.036	8.80	10
Cattle, Horses, Sheep	-0.075	7.63	19
Sheep, Horses	-0.049	7.63	8
Cattle, Rabbits, Sheep	-0.038	7.25	4
Donkeys	-0.035	7.00	3

Bold highlights results of interest with robust sample sizes

Generalized linear modelling illustrates that overall species richness increases as bryophyte and forb abundance increase in response to decreased vegetation height and grazing by combinations of donkeys, horses and rabbits (Figure 2).

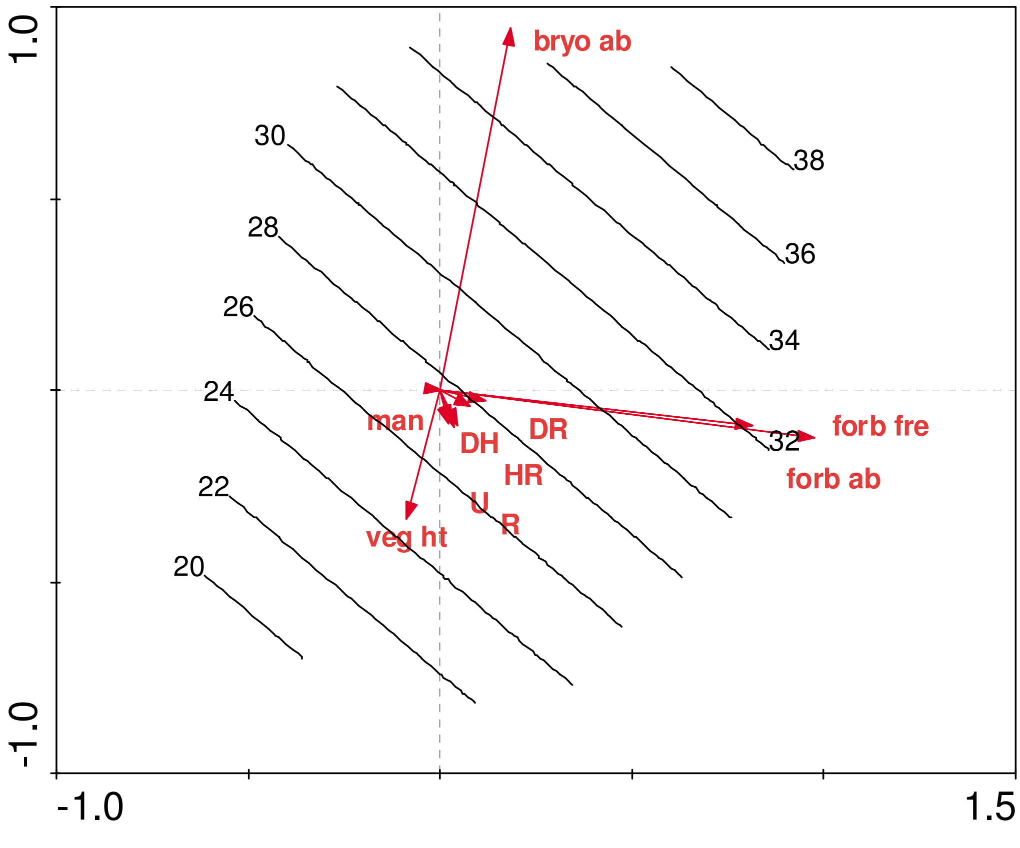

Figure 2. Variation in species diversity in relation to management gradients. The contour lines were generated in Canodraw for windows using GLM. The values refer to species richness. Abbreviations (see Figure 1).

Variance partitioning was used to separate the effects of stock type and vegetation height with typically low percentages of variance explained. Grazing stock type explained 3.8% of variance and vegetation height explained 1.3% with 0.2% of the total variance explained by both variables unaccounted for. Two-way ANOVA was used to examine the response of forb abundance and species richness to stock type (ordinal variable with four levels) and vegetation height (continuous variable) (Underwood 1997). Heterogeneity of variance restricted the stock types to cattle, cattle and sheep, horses and sheep. Stock type resulted in significant differences in forb abundance although vegetation height did not (Table 4). There were significant interaction effects between stock type and vegetation height; however, the ecological significance of the difference is limited as mean forb abundance does not vary by more than 10% (Table 3, Figure 3). Species richness varies significantly with both stock type and vegetation height but the interaction is not significant (Table 4). The ecological significance of variation in species richness is limited as mean species richness varies from 25.9 to 30.7 with robust data (Figure 4) although the overall range is larger (Figure 2). Post testing did not reveal any significant differences (P <0.05) between sheep grazing and other stock types (cattle, horses, cattle and sheep) at equivalent sward heights of <10cm.

Table 4. Two-way ANOVA: stock type, vegetation height, forb abundance and species richness

source	Forb abundance		Species richness	
	F	P	F	P
Model	3.60	0.0007	9.35	0.0000
Grazing stock type	2.78	0.0397	2.68	0.0454
Vegetation height	0.28	0.5940	10.58	0.0012
interaction	3.71	0.0112	0.23	0.8723

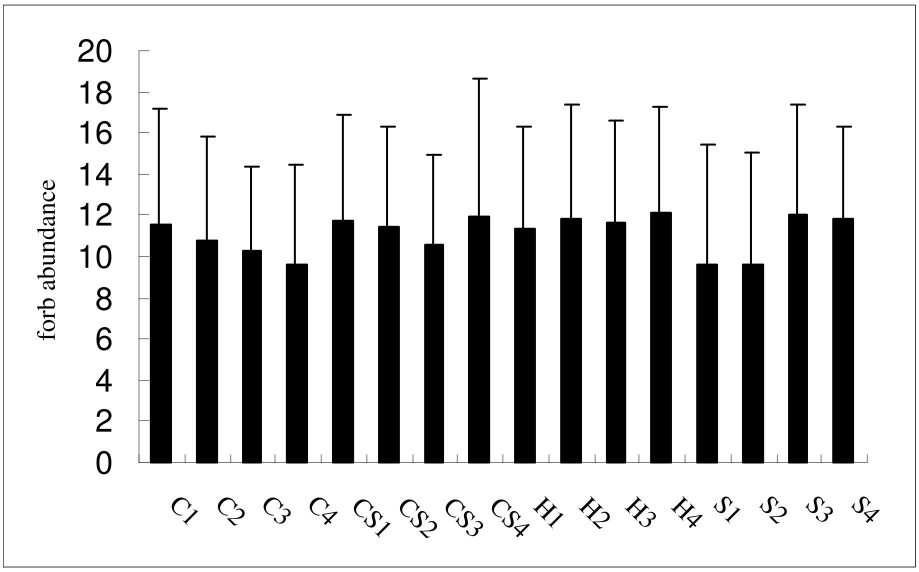

Figure 3. Forb abundance in relation to stock type. Abbreviations: 1 (vegetation height <5), 2 (vegetation height 5-10), 3 (vegetation height 10-20), 4 (vegetation height >20); C (cattle), CS (cattle and sheep), H (horses), S (sheep).

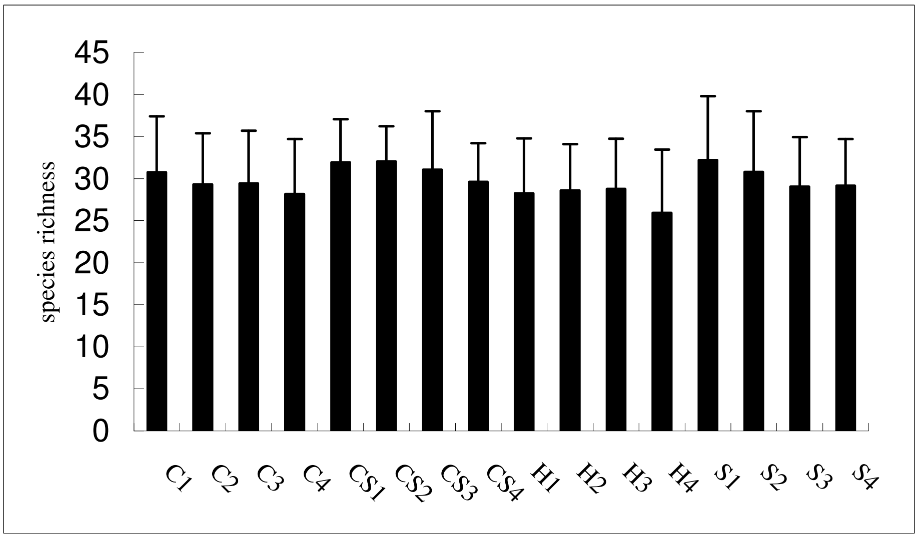

Figure 4. Species richness in relation to stock type. Abbreviations: 1 (vegetation height <5), 2 (vegetation height 5-10), 3 (vegetation height 10-20), 4 (vegetation height >20); C (cattle), CS (cattle and sheep), H (horses), S (sheep).

5. DISCUSSION

5.1 Paucity of direct comparisons and information regarding land use history

Despite a large literature base regarding general grassland management there is a paucity of published evidence concerning the use of specific stock types and stock densities on MG5 grassland. The use of data, from closely allied community types such as *Alopecurus pratensis-Sanguisorba officinalis* (MG4) or *Anthoxanthum odoratum-Geranium sylvaticum* (MG3) grassland, would increase the available data, but the management contexts differ considerably as the former is flood meadow whilst the latter is often managed as hay meadow.

Only three comparisons of stocking impact on MG5 exist. One comparison of sheep and cattle grazing (Roberts 1928) consists of a single site comparison with limited information available regarding details of stocking rate and floristic change only reported for some species. A higher quality experiment (Warren *et al.* 2002) produced broadly consistent results but was concerned with resown MG5 which cannot be assumed to have the same response as long established vegetation. Further high quality comparative work examines the difference between horses and cattle (Gibson 1996, 1997). These studies were concerned with plant species only and their utility is limited by lack of knowledge regarding previous land use history.

Lack of detailed knowledge regarding previous land use history is especially problematic given the lack of long term experimentation or monitoring. This leads to fallacies regarding the age of old meadows. For example the presence of ridge and furrow is accepted as absolute confirmation of the absence of ploughing since medieval times or earlier, even though some of it is relatively recent ‘narrow rig’ from 18-19th Century Parliamentary enclosure (Rodwell 1992). Likewise, large anthills are considered signs of antiquity despite developing over relatively short timescales (decades) in some instances (Gibson *pers comm.*). The lack of long term data regarding changes in agricultural practice from hay-making to pasture also presents a serious problem even where it is established that land has not been ploughed. This is compounded by lack of information regarding land improvement since the 1940s.

Experimental work often fails to report management activities adequately. Even where stock details are available comparisons and starting points are too varied for meaningful synthesis. Experiments and multivariate analyses agree that land use history has an important influence on species composition but are too context specific and diverse in management and outcome for general conclusions to be made.

5.2 Lack of information regarding taxa other than vascular plants

Current inventories of grassland resource and management guidelines mostly focus on vascular plants with little information available regarding other taxa. Most studies of invertebrates suggest that abundance and diversity reach a peak at intermediate grazing or cutting intensities (Andrzejewski & Gyllenberg 1980, Morris 1981, Watts *et al.* 1982, Morris & Plant 1983).

It is assumed that bird diversity also peaks at intermediate levels as most farmland bird species are insectivorous during the breeding season and intensive grazing is directly detrimental for many ground-nesting birds because of increased exposure to nest predation and trampling of nests (Tucker 1992, Vickery *et al*. 2001, Buckingham *et al.* 2006). Examples of bird reliance on invertebrates for food are cited by Buckingham *et al* (2006) with breeding productivity in Cirl buntings limited by grasshopper availability (Evans *et al*. 1997), and chick and body condition in skylarks and corn buntings related to Lepidoptera availability (Brickle *et al*., 2000; Donald *et al*., 2001). The abundance of grasshoppers (and probably Lepidoptera) is reduced by intensive grassland management (vanWingerden *et al.,* 1992).

As the diversity of phytophagous insects is positively correlated with plant species diversity, plant architectural diversity, occurrence of different vegetation patches and plant productivity (Strong *et al.*1984; Siemann 1998; Waide *et al.* 1999) there is a presumption that intermediate grazing levels benefit biodiversity across taxa. However, some experimental work indicates that insect diversity is higher in ungrazed sites than grazed sites (Kruess and Teja 2002) whilst others find no relationship between plant species richness at the local scale and bird diversity (Part and Soderstrom 1999).

This suggests that there are tradeoffs between different taxa which have different management requirements. Maximising the biodiversity of plant, insect and bird taxa may not be realistic conservation objectives on the same MG5 sites. The management of other taxa such as fungi in MG5 remains unstudied experimentally.

5.3 Analysis of raw data from welsh MG5 grassland

Analysis of the 1600 quadrats from high quality MG5 sites across Wales demonstrate that stock type and vegetation height significantly impact on plant community composition, species richness and forb abundance. Mean forb abundance for horse, cattle and sheep-grazed sites are 11.73, 10.65 and 10.48 respectively. Thus the direct differences between stock types are not ecologically significant. However, this does not account for variation in differential stock type impacts at different grazing intensities. Although there is not a direct relationship between stocking intensity and vegetation height (Kirkham *et al.* 2003), intensively grazed swards will clearly be shorter than extensively grazed swards, all other factors being equal. Vegetation height has an important impact on overall plant species richness because high bryophyte diversity is associated with shorter swards. It also has important interaction effects with stock type. Our analyses of available vegetation data show that maximising forb abundance and species richness is achieved by maintaining sward heights at 0-10 cm for cattle and horses, although maximum forb abundance is found at sward heights >10cm for sheep, perhaps suggesting that MG5 grassland cannot support sheep grazing at the same intensity as cattle and horses if forb abundance is to be maintained. However, post tests show no significant difference between stock types at equivalent sward heights >10cm. Conclusions regarding other stock types and combinations are constrained by sample size and heterogeneity of variance.

Conclusions regarding individual plant species must also be tentative, partly due to potential confounding but also because of the problems of interpreting multiple comparisons. However, the presence of *Centaurea nigra, Leontodon hispidus, Lotus corniculatus, Pimpinella saxifrage, Potentilla erecta* and *Succisa pratensis* is strongly associated with forb abundance implying that high intensity sheep grazing is more damaging for these species than high intensity cattle grazing. Their occurrence is also negatively correlated with *Trifolium repens* and *Cerastium fontanum*, both of which are dependent upon the debilitation of potential dominants for survival and are frequent in heavily grazed habitats (Grime *et al.* 1992). The RDA implies a relationship between high forb abundance and combinations of equines, rabbits and ungrazed habitat (Figures 1, 2; Table 3) but this is confounded by the high sward heights and small sample sizes associated with these stock types, and probably indicates a relationship between *Centaurea nigra, Leontodon hispidus, Lotus corniculatus, Pimpinella saxifrage, Potentilla erecta* and *Succisa pratensis* abundance and low intensity grazing rather than a particular stock type. However, it has been suggested that for *Succisa pratensis* at least, opening up the turf (as equines and rabbits do) may facilitate seedling recruitment by providing regeneration niches (Smith *pers comm.*).

Robust interpretation of the phase II habitat data is complex primarily because the differences between stock types are small and inferential judgments must be made to interpret vegetation height in terms of grazing intensity. It should also be borne in mind that although the original data is high quality, the previous landuse history of the sites is unknown and the intensity of sampling effort is insufficient to assume that individual samples are representative of management units as a whole. Considerable subjective judgments were required when assessing the management implications of the analysis many of which could not be defined *a priori* because they were unanticipated. The relative weighting of evidence from the systematic review and the analysis also requires subjective value judgments, The relatively low forb diversity associated with sheep grazing at <10cm sward height is consistent with the data reported in the literature and suggests that sheep grazing does reduce forb diversity. However, the difference is small and not statistically significant. This can be explained because the dataset represents high quality sites, so the extremes of ‘bad grazing’ management are excluded by definition. Nonetheless, weighting the non significant results, information from the literature and rational explanation of both produces potential variation in interpretation and considerable uncertainty. The mechanistics underlying the reduction in forb abundance and species richness apparent at high sheep grazing intensities are subject to even more uncertainty, but could be due to increased selectivity of sheep compared to cattle or the lack of bare ground niches created by sheep in contrast to cattle (Jefferson *pers comm.*).

6. REVIEWERS' CONCLUSIONS

6.1 Implications for conservation

Available evidence suggests that conservation managers considering grazing on MG5 sites should primarily be concerned with grazing intensity. Grazing at low intensities increases sward height and forb diversity but overall plant species richness is limited as bryophyte abundance declines.

Choice of stock type appears to be less critical than grazing intensity but there is some evidence that sheep grazing can result in lower forb diversity than cattle grazing at high stocking rates. There is no empirical evidence regarding the impact of different breeds on MG5 grassland, but we assume the impact of breed is negligible given that differences between species of stock are not large.

Further evidence regarding grazing intensity-stock type interactions is noticeably lacking, precluding prediction regarding stock type impacts at given stocking intensities. Lack of detailed knowledge of land-use history is a major impediment and there is little information regarding taxa other than vascular plants.

Managers must balance changes in bryophyte abundance, forb diversity and plant species richness to achieve tradeoffs appropriate to their conservation objectives. As different taxa have different (and often unknown) management requirements, the poor evidence-base necessitates a flexible site-based adaptive management and rigorous monitoring where grazing of important MG5 pastures is undertaken.

6.2 Implications for further research

Robust empirical evidence for the efficacy of low intensity grazing to achieve conservation objectives on MG5 pasture is lacking. High quality comparative work comparing cattle and horse grazing is available together with lower quality information regarding sheep. A comparative dataset of 1600 grassland samples is also available. This work suggests that heavy grazing reduces plant and forb diversity and that grazing by sheep reduces diversity more than grazing by cattle. However, considerable uncertainty surrounds these results that are derived from comparisons and one short-term factorial experiment on restored MG5. More robust long-term experimentation and monitoring are required to develop the necessary evidence-base. Many important questions remain unanswered. In particular, more information is required regarding stock type-grazing intensity interactions and very little is known about grazing impacts beyond local variation in plant species richness.

Well controlled and replicated grazing experiments are expensive, and whilst these provide the most robust evidence (at habitat scale), there is considerable scope for further correlative work such as that presented in the analyses and by Gibson (1995; 1996). Linking the long-term management of sites (information held by DEFRA) with information regarding their current condition or change in condition (information held by statutory agencies) could yield interesting results.

7. ACKNOWLEDGEMENTS

We would like to acknowledge the support of CCW staff particularly Terry Rowell, David Stevens, Stuart Smith, Clive Hurford and Dan Guest. Colleagues at CEBC, University of Birmingham especially Tam Kabat and Jon Sadler. We would also like to thank everyone who provided support or valuable feedback particularly Nigel Critchley, Richard Jefferson, Sophie Lake, Alistair Church, Clare Pinches, Jane MacIntosh, Vicky Morgan and Jim Swanson.

8. POTENTIAL CONFLICTS OF INTEREST AND SOURCES OF SUPPORT

No conflicts of interest to be declared. This systematic review is funded by NERC.

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10. APPENDICES

Appendix One: Table of included studies.

Table 2A: Summary of relevant review articles: individual species

Reference	Subject	Intervention	Outcome
Adams (1955)	*Succisa pratensis*	Response to biotic factors includes grazing and trampling	"The rosette leaves are partially protected from grazing and plants often occur in heavily grazed areas." When leaves were subject to repeated defoliation experimentally, flower stems became shorter. Lateral shoots replace the terminal bud if it is grazed off. Rosettes are resistant to trampling (although leaves in bud and flower stems may be damaged) therefore *S. pratensis* is common on path margins.
Beddows (1959)	*Dactylis glomerata*	Grazing	Grazing during spring/summer results in dominance whereas grazing in autumn/winter eliminates *D.glomerata* form mixed swards. High water table causes the plant to become unpalatable to stock even when young and it is sensitive to trampling impacts.
Beddows (1961)	*Holcus lanatus*	Grazing	The frequency of *H.lanatus* is related to grazing severity with severe defoliation resulting in few surviving plants. It is sensitive to trampling.
Bullock and Pywell (2005)	*Rhinanthus* in diverse grassland	Grazing	*Rhinanthus minor* does not respond well to heavy grazing.
Burdon (1983)	*Trifolium repens* in grassland	Grazing	Frequent intense grazing favours *T. repens.* It is resistant to trampling and grows well on cattle dung. Grazing by sheep may contribute to the maintenance of leaf mark polymorphisms.
Harper (1957)	*Ranunculus acris*	Grazing	*R.acris* is avoided by cattle, horses and sheep because of the acridity of protoanemonin released in its sap. It therefore spreads in heavily grazed communities
Harper (1957)	*Senecio jacobaea*	Grazing	*S. jacobaea* is toxic to cattle and horses (and therefore avoided unless grass is in short supply e.g. in droughts). Sheep do eat *S. jacobaea* therefore switching from cattle to sheep reduces the vigour of the plant. Trampling inhibits growth but does not kill the plant or prevent establishment.
Lodge (1959)	*Cynosurus cristatus*	Grazing	Foliage and young infloresences are grazed by cattle, sheep and horses. Jones cites Tansley (British Isles p512) "flourishes better in pastures than permanent hayfields".
Pfitzenmeyer (1962)	*Arrhenatherum elatius*	Grazing	*A. elatius* is usually absent from grazed swards. It doesn't recover well after grazing due to the paucity of its basal axillary buds (although some ecotypes on chalk are adapted to tolerate grazing). The species is sensitive to trampling
Richards and Clapham (1941)	*Juncus effusus*	Grazing	*J. effusus* is readily grazed by cattle but not easily eliminated from pasture by grazing alone. Resistant to trampling and tolerant of annual cutting.
Westbury (2004).	*Rhinathus minor*	Response to biotic factors including grazing and cutting management	The reliance of R. minor on its hosts for much of its nutrition suggests that the partial defoliation of a host could reduce the performance of R. minor. However, when all meadow vegetation except R. minor was clipped at the soil surface, no significant effect on its fecundity or survival was observed. Information from other sources (Smith et al. 2000) reiterated.

Table 2B: Summary of relevant review articles: population/communities

Reference	Subject	Intervention	Outcome
Augustine & McNaughton (1998)	Plant communities	Grazing by ungulate herbivores	Grazing has variable effects. Many studies show that selective herbivory leads to the dominance of unpalatable, chemically defended plant species but many studies show that intensive long-term herbivory does not lead to the invasion of unpalatable species and can even increase the dominance of highly palatable species. High levels of nutrient inputs or recycling and an intermittent temporal pattern of herbivory (often due to migration) are key factors increasing the regrowth capacity of palatable species and hence maintaining their dominance in plant communities supporting abundant herbivores.
Bardgett and Cook (1998)	Agricultural grasslands	Management including grazing	Bardgett et al. suggest that low input grassland farming systems are optimal for increasing soil biotic diversity and hence self-regulation of ecosystem function. Specifically, reductions in Collembola numbers were associated with increased sheep stocking density of a lowland perennial ryegrass (Lolium perenne) grassland (MG6). These responses were attributed to changes in soil pore space and surface litter, both of which were reduced with increased sheep grazing intensity.
Bardgett, Wardle et al. (1998).	Plants	Grazing	Plant physiological responses to herbivory influence both soil organisms and key soil processes such as decomposition and nutrient mineralisation in terrestrial ecosystems. However, the direction of these effects are unpredictable because several mechanisms are often involved and because of the inherently complex nature of soil food-web interactions therefore further work is required to predict impacts.
Critchley et al.	Semi-natural grassland in England and Wales including MG5	Agri-environment management including grazing	Results of botanical monitoring programmes, of duration up to 8 years for agri environment schemes, are reviewed in the context of the UK Biodiversity Action Plan (BAP). Some signs of reversion to grassland of biodiversity value (restoration) were detected in 9 out of 30 samples of agriculturally improved or semi-improved grassland. Rehabilitation or restoration usually coincided with low fertiliser input or changes in grazing intensity, and often occurred in western locations or the upland fringe. Deterioration was mostly due to inappropriate grazing intensity or altered hydrological regime.

Table 2B continued: Summary of relevant review articles: population/communities

Reference	Subject	Intervention	Outcome
Menneer et al. (2004)	Legume based pasture with most references from New Zealand (affinities to MG5?)	Management including grazing	No clear relationship persists between stock type (cattle or sheep) and pasture production (partly due to confounding by stocking density). Figures are also presented comparing the impact of cattle and sheep on soil bulk density (again confounded by stocking duration and density). Summaries of grazing management strategies to increase *Trifolium* content are presented with sheep grazing and mid-summer cutting identified as marginal in comparison to other grazing and cutting regimes.
Rodwell (1992)	MG5	Grazing (no information on stock type)	Grazing in the summer, particulary heavy grazing, can decrease the richness of the sward as early flowering species cannot set seed and there is an expansion of rosette hemicryptophytes. Mowing exerts a similar effect to grazing but frequent mowing will result in succession to MG6. Ungrazed stands revert to *Arrenatherum* or Mesobromion swards with scrub invasion possible.
Rook et al. (2004)	Pasture (no information specifically on MG5)	Grazing by different stock types and breeds	The main mechanism by which grazing livestock affect biodiversity in pastures is the creation and maintenance of sward structural heterogeneity, particularly as a result of dietary choice. We identify lack of understanding of the currencies used by animals in their foraging decisions and the spatial scale of these decisions as major constraints to better management. We conclude that there are important differences between domestic grazing animal species in their impact on grazed communities and that these can be related to differences in dental and digestive anatomy, but also, and probably more importantly, to differences in body size. Differences between breeds within species appear to be relatively minor and again largely related to body size. We conclude that there is an urgent need to understand the genetic basis of these differences and also to separate true breed effects from effects of rearing environment.
Tallowin (1997)	Mesic grassland including MG5	Management activities including grazing	This review is concerned with the impact of different management techniques on the agricultural productivity of grasslands rather than their biological value. High biodiversity grasslands are less productive, but more work is required to determine the impact of different stocking types especially older breeds.
Part and Soderstrom (1999)	Mesic pastures in Sweden (affinity to MG5?)	Management activities including grazing	Results suggest that there is no relationship between plant species richness at the local scale and bird diversity. Literature (but not data) on birds, invertebrates and plants suggests that that intermediate grazing levels will maximise biodiversity benefit
Crofts and Jefferson (1999)	Grassland including MG5	Management activities including grazing	Generic grassland management guidance providing information regarding the impact of grazing on plants and the different attributes of grazing stock (breeds and species) as well as practical advice on livestock management. Some references are directly relevant to MG5 management.

Table 3A: Summary of relevant experimental studies: unspecified grazing regimes

Reference	Subject	Intervention	Outcome	Methodology
Agnew (1961)	*Juncus effusus*	Grazing and growth form of *Juncus effusus*	*Juncus effusus* occurs in clumped and unclumped growth forms. Trampling by cattle allows establishment of seedlings (by reducing competition). The clumped habit is maintained by slow peripheral growth and is found i) on paths (human trampling), ii) sheep paths, and iii) where sheep congregate (around sheep folds, on the lee side of walls).	PhD experiments and "informal" observation
Ejrnaes 1995	MG5 grassland with U1, U3 and CG2 (Denmark)	Grazing (stock type and details unknown)	Species composition was recorded on 50 plots on grassland (mostly MG5).Land use history including grazing was subjectively scored. DCA and CCA ordinations showed an overall influence of land use history on species composition. DCA axis 1 was strongly correlated with species diversity of vascular plants. High species diversity is proposed to result from the combined action of high pH, high $CaCO_3$ content, high age of turf, grazing and absence of fertilization.	Ordination of 11 grassland sites (n=50) all but one subject to grazing.
Brys, Jacquemyn et al. (2004)	*Primula veris* in Galio-Trifolietum (Belgium)	Grazing v mowing and no management	*Primula veris* should be managed by mowing rather than grazing, but late grazing is preferable to early grazing. No management is the worst option.	Factorial experiment run for 5 years
Wagner and Luick (2005).	Generic grassland (Germany)	Traditional meadow management v extensive grazing	Grassland management recommendations consistent with the EU Species and Habitats Directive (SHD) have been oriented to traditional land-use practice such as mowing once or twice a year. However, in Germany, traditional dairy-based agricultural systems are dramatically declining. A more realistic strategy is extensive grazing with livestock such as suckler cattle, sheep or horses, but it is not known if these systems maintain the structural and floristic potential of SHD grassland types. Structural differences between long-term grazing systems and neighbouring extensive meadows were investigated over four-years (2000-2004). Results show that long-term grazing systems maintain floristic composition and uphold SHD requirements. The most important variable, linking high floristic similarity of meadows and pasture managed by rotational grazing, is the regular use of intermediate mowing.	Comparative Study (German Language)

Table 3B: Summary of relevant experimental studies: Cattle

Reference	Subject	Intervention	Outcome	Methodology
Casler (1998)	Forage grasses	Grazing (cattle)	Robust evidence that cattle selectively graze *Dactylis glomerata, Phalaris arundinacea* and *Lolium perenne* but results are very context specific.	Rct to assess maximizing forage availability for cows by manipulating species composition
Casler and van Santen (2001)	*Festuca pratensis*	Grazing (cattle)	Naturalized meadow fescue accessions had greater apparent intake and preference and were lower in crown rust resistance than cultivated meadow fescue accessions.	Field experiment
Jantunen et al. (2002)	Mesic grassland with affinity to MG5 (Finland)	Grazing by cattle or horses v formerly grazed sites v ungrazed	Variation in floristic composition was explained by grazing and nutrient enrichment. Grazed sites had the lowest species richness and diversity.	Site comparison with multivariate ordination
Kruess and Teja (2002)	Mesic grassland in North Germany	Grazing by cattle (intensive and extensive) v short-term and long-term ungrazed grassland	The effects of grazing intensity on plant and insect diversity were examined in four different types of grassland (intensively and extensively cattle-grazed pastures, short-term and long-term ungrazed grassland; 24 study sites). Vegetation complexity (plant species richness, vegetation height, vegetation heterogeneity) was significantly higher on ungrazed grasslands compared to pastures but did not differ between intensively and extensively grazed pastures. However, insect species richness was higher on extensively than on intensively grazed pastures, established by suction sampling of four insect taxa (Auchenorrhyncha, Heteroptera, Coleoptera, Hymenoptera Parasitica) Insect diversity increased across the four treatments in the following order: intensively grazed<extensively grazed<short-term ungrazed<long-term ungrazed. The major predictor variable of differences in species diversity was found to be vegetation height.	Controlled trial (Each management was replicated six times)

Table 3B continued: Summary of relevant experimental studies: Cattle

Reference	Subject	Intervention	Outcome	Methodology
Kydd (1964)	Calcareous grassland with some affinity to MG5?	Different cattle grazing regimes v hay cut and control. (sheep grazing is mentioned in the introduction in connection with the treatments but not the methods)	The reaction of a downland pasture to different systems of cattle grazing is described and compared with an ungrazed control. Changes in ground cover during the season were characteristic for the species, and modified but not altered fundamentally by variations of grazing management. Changes in the cover of individual species from year to year were small between 1953 and 1955 but changes showed clearly in 1956 and 1957: these were most marked in treatment extremes.	Agricultural lattice experiment (controlled trial)
Luoto et al. (2003)	Mesic grassland in Finland	Grazing (cattle) within last 5 years v grazing within last 5-25 years v no grazing for >25 years	Termination of grazing caused a significant decline in vascular plant species diversity (The manuscript also looks at temporal change at a landscape level including fragmentation).	Field survey and ANOVA
Luoto et al. (2003)	Mesic grassland in Finland	As above	As above	As above
Putman (1991)	Mostly MG4 grassland. Staines moor contains MG5 in mosaic with U1 and MG6	Grazing by cattle and ponies	Patterns of grazing and dunging by cattle and horses at Port Meadow (Oxford) and Staines Moor (Greater London) were non-random and extremely consistent in both sites despite differences in stocking densities. Cattle and horses were aggregated in their distribution and did not use all areas of the common with equal intensity, even over a longer time scale. Both species tended to favour the same areas of the meadow overall.	Field survey
Pykala (2005)	Species rich mesic grassland in Finland	continuous seasonal cattle grazing (n = 10) v cattle grazing resumed 3–8 years ago after over 10 years of abandonment (n = 10) v overgrowing, abandoned over 10 years ago (n = 11).	Positive effects of cattle grazing were observed on most grassland plants, 34 species being significantly more frequent in grazed than in abandoned grassland and four in abandoned than in grazed grassland. The frequencies of most species in restored new pastures were between those observed in old and in abandoned pastures. Changes in species number with different Ellenberg indicator values showed that grazing increased the number of species indicating nitrogen-poor soils, high light intensity and low soil moisture, but decreased species indicating nitrogen-rich soils. Grazing was beneficial to indicator species of both high and low pH. Species numbers in new pastures were consistently between those of old and abandoned pastures.	Field survey and ANOVA

Table 3B continued: Summary of relevant experimental studies: Cattle

Reference	Subject	Intervention	Outcome	Methodology
Pykala (2003)	Species rich mesic grassland in Finland	Continuously cattle grazed v cattle grazing restarted 3-8 years ago v no grazing >10 years.	Plant species composition of the three pasture types was floristically different in multivariate analyses (non-metric multidimensional scaling). Total species richness, richness of grassland, plants, indicator plants and rare plants were highest in old and lowest in abandoned pastures in all studied spatial scales (0.25-0.8 ha, 1 and 0.01 m2). The results were congruent with different scales and species list definitions, suggesting that species density scale (1 m2) can be used as a partial surrogate for large scale species richness. Species richness of new pastures was 20% higher on 0.25-0.8 ha, 40-50% higher on 1 m2 and 30% higher on the 0.01 m2 scale compared to abandoned grasslands. Rare species showed insignificant response to resumed grazing. Despite problems in management quality, this study showed promising results of restoration of abandoned grasslands by cattle grazing on private farms. However, populations of several rare grassland plants may not recover with present cattle grazing regimes. Management regulations in the agrienvironmental support scheme need to be defined more precisely for successful restoration.	Field survey, ordination and ANOVA
Pykala (2005)	Species rich mesic grassland in Finland	Continuously cattle grazed v cattle grazing restarted 3-8 years ago v no grazing >10 years.	Species richness was higher among most species trait groups in old than in abandoned pastures and showed some recovery in new pastures. More pronounced differences were found per m2 than per grassland patch. Richness of perennial and biennial plants was in order old > new > abandoned pastures both per m2 and per grassland patch, but richness of annual plants was significantly higher only per grassland patch. Grazing increased the richness of hemicryptophytes and chamaephytes and decreased that of geophytes both per m2 and per grassland patch. Richness of small and medium-sized plants was higher in grazed than in abandoned grasslands. Only richness of the tallest species (height > 80 cm) was lower in grazed grasslands. In mesic grasslands natural factors limit plant growth less than in dry or wet grasslands. Because of this the number of groups of species with different species traits benefiting from grazing is higher in mesic than in dry or wet areas.	Field survey, ordination and ANOVA

Table 3B continued: Summary of relevant experimental studies: Cattle

Reference	Subject	Intervention	Outcome	Methodology
Rossignol et al. (2006)	Mesic grassland in France with affinity to MG5 and an additional halophytic element due to it's coastal location	Grazing by Cattle, horses and a control	The aim of this study was to determine whether the spatial heterogeneity of grassland vegetation structure would lead to spatial heterogeneity in the net nitrogen mineralisation process in the soil and therefore in the quantity of mineral nitrogen available for the plants.Grazing by cattle or horses significantly stimulated net nitrogen mineralisation compared to ungrazed conditions and led to spatial heterogeneity in mineralisation rates.	Treatment and control plots with ANOVA based analysis

Table 3C: Summary of relevant experimental studies: Sheep

Reference	Subject	Intervention	Outcome	Methodology
Hellstrom (2003)	*Agrostis-Alchemilla* sward with affinity to MG5	Sheep grazing v no grazing	Abandoned pasture restored by sheep grazing over five years showed increase in species richness and abundance of small forbs. Propagule availability and the dominance of tall species are postulated as restricting the increase in species richness.	Replicated controlled trial

Table 3D: Summary of relevant experimental studies: cattle or horses v sheep

Reference	Subject	Intervention	Outcome	Methodology
Warren et al. (2002)	MG5 (created by restoration treatment consisting of ploughing and sowing)	Some interventions relate to restoration rather than maintenance of conservation value but cattle are compared to sheep and grazing is compared to cutting	Plots grazed by cattle were found to contain more than twice as many sown species as did plots grazed by sheep. Cattle-grazed treatment (sown plots) experienced no decline in the number of sown species persisting. In this case, community change occurred as a result of an increase in cover of two non-sown species, *T. repens* and *R. repens*. The vegetation that developed in the sheep-grazed plots was species-poor, it had <1% cover of forbs by the sixth year and was dominated by the sown grasses possibly due to selective grazing. The biennials *Cirsium vulgare* and *Senecio jacobaea* which were generally tall and unpalatable species, thrived under grazed-only treatments but did less well when prevented from flowering by cutting. In contrast, the low-growing perennial forbs *Ranunculus repens* and *Trifolium repens* became more abundant when the vegetation was cut, but not under conditions of extreme defoliation associated with sheep grazing.	Factorial ANOVA based design with regression to deal with time elements
Gibson (1996)	MG5	Grazing by cattle v horses	Species of grazer has a minor impact compared to intensity of grazing. Horses do damage MG5 sites but only at high grazing intensities. There are subtle variations in like-for-like impact, and these are valuable in themselves. Degradation at high grazing intensities is manifest as a reduction in floristic species richness and loss of important indicator species.	Structured Survey
Gibson (1997)	MG5	Grazing by cattle v horses	Extension of Gibson (1996) to include sites out with Worcestershire. The results were confirmed as generally applicable across England.	Structured Survey
Roberts (1928)	Pasture including MG5 (N Wales)	Cattle v sheep	Extensive biomass samples were taken from eleven pastures in four regions of N Wales. These fields have different management histories. Two fields in the Conway valley were compared. Log Mawr is grazed heavily by cattle from 1st April to mid-September whilst Pant y Carw has been stocked with sheep (100sheep to 18 ha) for the last six years. Until the last few years the fields had similar management histories (no manure input, sheep or horse grazing for 20 years). "The harmful effect of exclusive sheep grazing is very pronounced. It has reduced the number of species (15+ to 11+). Smooth stalked Meadow Grass and meadow fescue have been completed suppressed; cocksfoot is near vanishing point (in comparison to the cattle grazed site). Unfortuately, most forb species are lumped together as miscellaneous plants. These are reduced in overall biomass and diversity at the sheep grazed site, although Ranunculus bulbosus and chickweed (cerastium vulgatum?) persist.	Site comparison

Appendix Two: Table of excluded studies.

Characteristics of studies viewed at full text and excluded (wrong subject or intervention)

Reference	Subject	Intervention	Outcome
Alder (1970)	MG6	NA	NA
Bayliss, Helyar et al. (2003)	MG4 and MG5 meadows and pastures	No information on grazing (authors contacted)	Although there is no information on grazing, the raw data provides a potentially useful snapshot of MG5 floristic composition from a number of sites in the Thames valley, which could subsequently be linked to management (authors contacted for data unsuccessfully).
Bayliss, Simonite et al. (2005)	MG4 and MG5 meadows and pastures	No information on grazing.	See above
Blackstock, Rimes et al. (1999)	Semi-natural grassland in England and Wales including MG5	No information on grazing.	There are 1802 MG5 sites in England with a further 750 in Wales. Although there is no information on grazing, the raw data provides a potentially useful snapshot of MG5 floristic composition from these sites, which could subsequently be linked to management.
Buhler and Schmid (2001)	*Succisa pratensis* in calcareous fen	NA	NA
Bullock, Franklin et al. (2001)	MG6/MG7	NA	NA
Cuomo et al. (1999)	Improved *Medicago sativa* grassland in Minnesota	NA	NA
Davies (1997)	UK Pasture but no information on MG5 (MG6 and hill pasture discussed in relation to grazing)	NA	NA
Di Giulio (2001)	Limestone Grassland Swiss Jura	NA	NA
Fenton (1931)	Sown leys	NA	NA
Fenton (1931)	Improved grassland	NA	NA
Fischer and Wipf (2002)	Subalpine meadows	NA	NA
Fisher et al. (1996)	Extensively managed sward in Scotland	Sowing of forb and grass species and subsequent management	NA
Frankow-Lindberg (1997)	*Trifolium* dominated sward. Nova-Scotia	NA	NA
Fuller (1999)	British grazing land generally	NA	NA
Gooding and Frame (1997)	*Lolium-Trifolium* sward	NA	NA
Haines-Young et al. (2003)	Generic vegetation change across Britain	NA	NA

Hansson (2000)	*Agrostis-Briza-Arnica* grassland (Sweden)	NA	NA
Hodgson (2005)	Grassland in Central England	No information on grazing.	Comparative studies of grassland types but no information on grazing management
Hodgson (2005)	Grassland including MG5 in England	No information on grazing	There is an exponential increase in financial benefit from intensification of grassland and it is associated with a decline in biodiversity
Hopkins (1999)	Grassland including MG5	No information on grazing	Pre disturbance treatments e.g. turf-removal, harrowing, improve establishment of sown seed resulting in increased botanical diversity in pastures and meadows
Hulina (1984)	*Arrenatherum* grassland in Croatia	NA	NA
Jones and Turkington (1986)	*Lotus corniculatus*	No information on grazing by domestic stock	*L. corniculatus* is very tolerant of rabbit grazing
Le Roux et al. (2003)	*Arrhenatherum elatius* grassland	NA	NA
Lindborg and Eriksson (2004)	Mesic grassland in Sweden	NA	NA
Lithner (2005)	Acid grassland in Sweden	NA	NA
Lopez-Marino et al. (2000)	Spanish grasslands managed as hay meadows	NA	NA
Milchunas and Lauenroth (1993)	Global grasslands (UK grasslands included in analysis were not MG5)	NA	NA
Muller (2002a.b)	Mesic grassland including hay meadows but not pastures	NA	NA
Neilson et al. (2002)	Upland MG6	NA	NA
Newton et al. (2003)	Scottish grasslands	No details of management	NA
Pakeman (2004)	Scottish grasslands but not MG5	NA	NA
Petersen et al. (2004)	*Deschampsia flexuosa* grassland	NA	NA
Pietola et al. (2005)	Recently sown swards	NA	NA
Pozzi and Borcard (2001)	*Bromus erectus* grassland in France	NA	NA
Proulx and Mazumder (1998)	Global grazing experiments (no MG5)	NA	NA
Pykala et al.	Species rich mesic grassland in	Ungrazed grassland	NA

(2005)	Finland		
Pywell et al. (2002)	Grassland sites including MG5 but managed as meadows not pasture	Different restoration treatments (sowing mixtures) with hay cutting and aftermath grazing (sheep) as follow up	NA
Rochon et al. (2004)	Legume based pasture	NA	NA
Rosen and Bakker (2005)	Limestone grassland (Sweden)	NA	NA
Smith et al. (1996)	MG3	NA	NA
Smith et al. (1996)	MG3	NA	NA
Smith and Rushton (1994)	MG3	NA	NA
Somodi et al (2004)	Various steppe grassland types not analogous to MG5	NA	NA
Svenning (2002)	General open habitats with no specific reference to mesotrophic grassland MG5	NA	NA
T, A. G. (1937)	Book review regarding soil classification of welsh grasslands (no grazing information)	NA	NA
Taylor (1936)	General discussion of the impact of animals on plants (no information regarding mesotrophic grasslands)	NA	NA
Twerdoff et al. (1999)	*Bromus* grassland in Canada	NA	NA
Verhulst et al. (2004).	Hungarian vineyards and grassland (Peszéradacs meadows)	NA	NA
Walker et al. (2004)	British and Dutch grassland including MG5	Interventions relate to restoration rather than maintenance of conservation value	
Watkinson and Ormerod (2001)	Generic grassland	No information about grazing impacts	
Watt, A. S. (1981) a,b.	Breckland grass-heath		

Smith et al. (2000)	MG3	experimental plots under several cutting and grazing treatments	
White et al. (2004)	*Lolium perenne*, *Nertera setulosa* and *Centella* spp swards	NA	NA
Wilberforce et al. (2003)	Reseeded grassland	NA	NA
Anderson and Briske (1995)	Transplant garden. Texas	NA	NA
Freckman et al. (1979)	Californian grassland	NA	NA
Smith et al. (2000)	MG6	NA	NA
Morton Boyd (1960)	Machair	NA	NA
Hayes and Sackville-Hamilton (2001)	MG6/7	NA	NA
Fuller (1987)	Generic grassland including MG5 (UK)	Drainage, ploughing, inorganic fertilizer	NA
Seastedt et al. (1988)	Xeric grassland (South Dakota)	NA	NA
Berendse et al. (1992)	Meadows (Netherlands)	Inorganic fertilizer, hay cut, sod removal	NA
Hopkins (1990)	Meadow and Pasture (GB)	No specific mention of grazing in pastures	
Jones (1933)	Pasture and *Lolium* ley (GB)	Variation in grazing timing and fertilizer application (it is assumed that grazing here refers to cattle but this is not explicit)	