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HOW DOES THE IMPACT OF GRAZING ON HEATHLAND COMPARE WITH OTHER MANAGEMENT METHODS?

Systematic Review

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SYSTEMATIC REVIEW SUMMARY

Background

Lowland heathland is a priority habitat for nature conservation throughout north-west Europe. One of the most important causes of the loss of heathland habitat has been a widespread decline in 'traditional' use of heathlands, which included light grazing, controlled burning and cutting of vegetation for use as fuel and animal fodder. As a result, many heathlands have reverted to scrub or woodland through a process of natural succession. Current management responses to this problem include the use of fire, cutting of vegetation and reintroduction of grazing. Although reviews and guidelines for the management of lowland heath exist, few attempts have been made to compare grazing with alternative management approaches, such as cutting or burning. This highlights the need for a critical review of the evidence, to identify the conditions under which grazing is likely to be most effective as a management approach, and to determine the relative impacts of grazing compared to alternative management interventions.

Objectives

To ascertain:

- How the impact of grazing on heathland compare with the impact of burning, cutting or no management?

- The effect of timing, extent, frequency, severity, and nature of grazing, cutting or burning on their relative impacts?

Search strategy

Electronic databases and web sites were searched using key words. Bibliographies were also searched and researchers were contacted to retrieve relevant material. Heathland manager experience was collated using a questionnaire survey.

Selection criteria

For the systematic literature search, studies or data were included in the review where the following criteria were met:

1. *Subject*: lowland heath (<200 m altitude).
2. *Intervention*: grazing, burning, cutting or no management.
3. *Outcomes*: Relevant outcomes are amount and type of bare ground; cover of ericoid dwarf shrubs and *Empetrum* or *Ulex* species; cover of pioneer, building, mature, degenerate and dead *Calluna/Erica* spp. and growth form of *Calluna*; cover of graminoids; cover of forbs; cover of bryophytes and lichens; cover of miscellaneous species which have negative conservation value if present above target thresholds; amount and type of scrub.
4. *Comparators*: Comparators (before and after or treatment and control) were required for studies to be included in meta-analytical synthesis.

Data collection and analysis

Study inclusion assessments were performed and the observed agreement between independent reviewers was “substantial” indicating that the relevance assessment was repeatable. Sufficient data existed to derive ratios comparing grass cover to ericoid cover and these were combined using random effects meta-analysis. Other outcomes were tabulated. Additional information collected included a questionnaire survey of heathland managers.

Main results

Despite the apparently large literature available on this topic, there is limited empirical evidence regarding the relative impacts of burning, grazing and cutting on lowland heath. Of 3431 references identified with potentially relevant titles and abstracts, 92 (<3%) were found to be relevant to management of lowland heath. A further 177 references were identified by searching the web (using search engines, web pages, WOS, EN files, RSPB files) and bibliographies of relevant material.

Only 13 of these had appropriate comparators; three examined the impacts of burning, three examined vegetation cutting, four examined grazing, and a further three examined the impacts of grazing and burning or cutting in combination.

Best available evidence indicates that grazing increases the ratio of graminoid plants relative to ericaceous dwarf shrubs. There is considerable variation in the impact of grazing, burning and cutting, and this variation is unexplained. Furthermore, it is not clear from these data, how grazing, burning and cutting compare in terms of their impact on vegetation and other outcome measures.

Reviewers’ Conclusions

- **Implications for conservation management**: Available evidence from meta-analysis suggests that grazing can result in an increase in the ratio of graminoids to ericoids on heathlands. However, there is very little evidence available on the relative impacts of burning, grazing and cutting on lowland heath. Evidence from studies excluded from meta-analysis because of the lack of a comparator, and the beliefs of heathland managers elicited using a questionnaire, suggest that negative impacts of grazing on some habitat attributes are widespread. However overall, a large majority of respondents (94%) believed that grazing has been effective in meeting at least one management objective. Monitoring the impacts of interventions before and after implementation and further experimentation are necessary in order to develop a robust evidence base regarding the relative impacts of these interventions.

- **Implications for further research:** Further research regarding the effects of heathland management is urgently required if a robust evidence-base is desired. Studies should include comparator(s) and baselines wherever possible. Replication should be accorded higher value than has been traditional as 70% of existing ‘high’ quality information lacks statistical significance owing to large variance and small sample sizes.

1. BACKGROUND

Lowland heathland is a priority habitat for nature conservation throughout north-west Europe. At the European level, heathlands are included in the Habitats Directive 92/43/EEC as "a natural habitat type of community interest whose conservation requires the designation of special conservation areas". Approximately 70,000 ha of lowland heath remain in the UK, which represents about 16% of its former extent. A UK Habitat Action Plan has been developed for lowland heathland, and a number of species associated with lowland heathlands are the focus of national Biodiversity Action Plans (BAPs).

One of the most important causes of the loss of heathland habitat has been a change in the pattern of land use (Webb, 1986). Specifically, there has been a widespread decline in traditional use of heathlands, which included light grazing, controlled burning and cutting of vegetation for use as fuel and animal fodder (Webb, 1998). In particular, the disappearance of grazing from lowland heath in the 20th century is often cited as the major cause of loss of heath vegetation in Europe (Harrison 1976, Bunce 1989, Webb 1990, Marrs 1993, Bullock & Pakeman 1996). As a result, many heathlands have reverted to scrub or woodland through a process of natural succession. This process now represents the main threat to communities of plants and animals associated with heathland habitats (Rose *et al.*, 2000). Nutrient enrichment (particularly deposition of nitrogen compounds emitted from intensive livestock farming, or from other sources), fragmentation, disturbance from developments (such as housing and road construction) and agricultural improvement (including reclamation and overgrazing) are also considered as current threats (UK BAP 2005).

Current management responses to address the declines in the extent and 'condition' of lowland heath include the use of fire, cutting of vegetation and reintroduction of grazing. The impacts of different management interventions on lowland heaths were reviewed by Bullock & Pakeman (1997), and Lake, Bullock & Hartley (2001), who found that there have been no definitive studies of the impacts of grazing on heathland species although general overviews are provided by Webb (1986) and Gimingham (1992). Introduction of livestock to heathlands has been the subject of some controversy. Public opinion is generally against grazing on heathlands (Alonso, 2005), and local opposition can be severe, particularly where fencing of heathland on common land is proposed for control of livestock (English Nature, 2005).

Few attempts have been made to compare grazing with alternative management approaches, such as cutting or burning (Lake, Bullock & Hartley 2001). This highlights the need for a critical review of the evidence, to identify the conditions under which grazing is likely to be most effective as a management approach, and to determine the relative impacts of grazing compared to alternative management interventions.

2. OBJECTIVES

2.1 Primary objective

To systematically collate and synthesise published and unpublished evidence in order to address the following questions:

1. How does the impact of grazing on heathland compare with the impact of burning, cutting or no management?

2.2 Secondary objectives

2. What effect do the timing, extent, frequency, severity, and nature of grazing, cutting or burning have on their relative impacts?

Table 1: Definition of the components of the systematic review question.

Subject	Interventions	Outcomes
Lowland heath in Great Britain (dry heath types H1-4, H6-12; wet heath types H3-5, M14-16, M21; grass heath of Suffolk Sandlings and Breck lichen heaths U1, CG7; other communities occurring in a heathland mosaic M13, M25, M33). Communities >200m are not considered lowland irrespective of floristic composition	Grazing V No management Burning V No management Cutting V No management	Amount of bare ground not including rock or stone (Wet/dry, vertical/sloping/ horizontal, undisturbed or heavily disturbed e.g. poached) Individual and combined cover of ericoid dwarf shrubs and *Empetrum*, *Genista* or *Ulex* species. Cover of pioneer (10-15cm height), building (40cm height), mature (60-100cm height), degenerate and dead *Calluna/Erica* spp. Cover of carpet, topiary and drumstick *Calluna* growth forms. Cover of graminoids: *Agrostis* spp., *Carex* spp., *Danthonia decumbens, Deschampsia flexuosa, Festuca* spp., *Molinia caerulea, Nardus stricta, Scirpus cespitosus;* **For dune heath only:** *Aira praecox, Ammophila arenaria, Phleum arenarium.* Cover of forbs: *Galium saxatile, Hypochaeris radicata, Lotus corniculatus, Plantago lanceolata, Potentilla erecta, Rumex acetosella, Scilla verna, Serratula tinctoria, Thymus praecox, Viola riviniana;* ***For limestone heath only**: Filipendula vulgaris, Galium verum, Helianthemum nummularium, Sanguisorba minor;* **For dune and maritime heath only:** *Armeria maritime, Corynephorus canescens, Erodium cicutarium, Filago minima,*

	Plantago maritima, Sedum acre, ***For wet heath only:*** *Anagallis tenella, Drosera spp., Genista anglica, Myrica gale, Narthecium ossifragum, Pinguicula spp., Potentilla erecta, Succisa pratensis.* Cover of bryophytes and lichens: *Cladonia* spp., *Dicranum scoparium,Hylocomium splendens, Hypnum cupressiforme, Pleurozium schreberi, Polytrichum* spp.,*Racomitrium lanuginosum;* ***For dune heath only:*** *Peltigera spp.;* ***For wet heath only:*** *Sphagnum spp.* Cover of miscellaneous species which have negative conservation value if present above target thresholds: *Rhododendron ponticum, Gaultheria shallon, Fallopia japonica, Cirsium arvense, Digitalis purpurea, Epilobium spp. (excl. E. palustre), Chameriun angustifolium, Juncus effusus, J. squarrosus, Ranunculus* spp., *Senecio* spp., *Rumex obtusifolius, Urtica dioica,* "coarse grasses" (e.g. *Holcus lanatus, Dactylis glomerata), Betula* spp., *Prunus spinosa, Pinus* spp., *Rubus* spp., *Sarothamnus scoparius, Quercus* spp.,*Hippophae rhamnoides*, *Pteridium aquilinum* Dense mats of acrocarpous mosses (*Campylopus introflexus*). Amount of scrub (mainly trees or tree saplings) above 1 m in height and in clumps, not as isolated trees (sparse or dense stands; structurally complex edge or simple edge; heathland vegetation as ground cover or modified ground cover)

3. METHODS

3.1 Question formulation

The specific question was formulated through discussion between the CEBC and UK-based stakeholder organisations (i.e. those with an interest in the results of the review). In total, eight stakeholder organisations were contacted and invited to comment on a draft of the proposed methodological protocol: Countryside Council for Wales (CCW); The Environment Agency (EA); English Nature (EN); Grazing Animal Project (GAP), Joint Nature Conservation Committee (JNCC); National Trust (NT); Royal Society for the Protection of Birds (RSPB) and Scottish Natural Heritage (SNH). The methodological protocol was also available on an open access website and viewers were specifically asked to contribute feedback.

The key elements of the question (subject, intervention and outcomes) are defined in Table 1. Relevant comparators were considered a pre-requisite for meta-analysis and are also defined in Table 1.

3.2 Search strategy

Relevant studies were identified through computerised searches of the following electronic databases:

1. ISI Web of Knowledge
2. Science Direct
3. Scopus
4. Index to Theses Online (1970-present)
5. Digital Dissertations Online
6. Agricola
7. Europa
8. English Nature's "Wildlink"
9. JSTOR

The search terms terms were:

1. heath* and graz*
2. heath* and sheep
3. heath* and cattle
4. heath* and ponies
5. heath* and horse
6. heath* and manage*
7. heath* and conservation
8. heath* and cut*
9. heath* and burn*

Additionally, ISI Web of knowledge was searched using the terms: heath and mow, dwarf and shrub and diversity, dwarf and shrub and structure, heath and goat, heath and pig, heath and restoration, heath and condition.

Publication searches were undertaken on conservation and statutory organisation websites (Agricultural Development and Advisory Service, Countryside Council for Wales, Centre for Ecology and Hydrology, Department of Environment Food and Rural Affairs, English Nature (with additional searches of the GAP and FACT websites), Environment Heritage Service NI, Joint Nature Conservation Committee (JNCC), National Trust, Royal Society for the Protection of Birds, Rural Development Service, Scottish Executive (SERAD), Scottish Natural Heritage, English/Welsh and Scottish Wildlife Trusts) 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. Authors, recognised experts and practitioners were invited to provide any missing material at the ninth national Heathland conference (8-10th August 2006, Aberdeen UK).

Foreign language searches were not conducted for this review. However, relevant studies were included, irrespective of geographical location.

3.3 Questionnaire survey

A questionnaire was designed to elicit the opinions of heathland managers regarding the impacts of grazing on lowland heathland, compared to other management approaches (specifically burning and cutting). The questions were designed to obtain information on the impacts of grazing on different attributes of lowland heathland habitats. Attributes were identified from recent summaries of the key habitat features of heathland, including the Common Standards Monitoring approach (JNCC 2004), Bacon (1998), Lake et al. (2001) and Offer et al. (2003) (see Appendix 3). These summaries provide information about the habitat requirements of species of conservation concern that are associated with heathland, including birds, reptiles, amphibians, invertebrates, vascular plants, lichens and bryophytes. A combined list of habitat attributes (Appendix 2) was produced by integrating information from these different sources.

Participants were invited to respond to 49 questions, which included both open and closed questions. The first 26 questions were open, and were designed to elicit background information on each site, including site name, location and characteristics; site management history; heathland condition prior to the (re)introduction of grazing; and details of current management approaches, including management objectives. The remaining questions were closed, and were designed to elicit information on the impacts of grazing on heathland attributes, using a five point Likert scale. In each case, respondents were invited to select an individual response option that 'best describes your belief about the impacts of grazing, with respect to the site with which you are familiar'. The options provided for each question related to the amount of change in each attribute resulting from the introduction of grazing, namely 'large increase', 'small increase', 'no change', 'small decrease', and 'large decrease'. There was only one exception to this structure, namely Q32, which asked whether the spatial structure of ericaceous shrubs has become 'more homogeneous' / 'less homogeneous' / 'no change'. Respondents were also invited to comment on what evidence they base their beliefs, with the options: 'formal monitoring using permanent plots', 'casual observations made personally', 'opinion received from others', 'a range of different monitoring methods', or 'other'.

The questionnaire was distributed via the following web sites:

- Nibblers Forum
- HeathNet

The questionnaire was emailed to the following groups:

- Wessex Conservation Forum
- JNCC lowland heath distribution list
- Lowland Heathland Habitat Action Plan Steering Group
- English Nature Heathland Network

In addition, areas with a lack of response were identified, and 60 phone calls were made to heathland managers identified using the Tomorrow's Heathland Heritage web site http://www.english-nature.org.uk/

3.4 Study inclusion criteria

Studies from the initial database searches were initially filtered by title and any obviously irrelevant articles were removed. Subsequently, the abstracts of the remaining studies were examined with regard to possible relevance using the subjects, interventions and outcomes defined in Table 1. This identified 3431 potentially relevant references in bibliographic databases of which a randomly selected 600 (18%) were assessed for relevance by a second independent reviewer.

Agreement on inclusion between the reviewers was initially deemed to be 'moderate' (Cohen's Kappa test: K = 0.47). Inclusion criteria were defined more precisely to exclude references to ambiguous land management and paleoecology where no empirical data regarding grazing management were presented. Agreement between independent reviewers was 'substantial' (K = 0.79) following this clarification. Studies were accepted for viewing at full text if it appeared that they might contain information pertinent to the review question, or if the abstract was ambiguous or missing, and did not allow inferences to be drawn about the article content.

3.5 Study quality assessment

Insufficient material with comparators was retrieved for meaningful study quality assessment. The sampling methodologies of studies included in meta-analysis were collated in lieu of formal study quality assessment (Table 2).

3.6 Data extraction

A single investigator abstracted information regarding relevant outcomes from quantitative studies with comparators into a Microsoft Excel spreadsheet and assessed study eligibility and suitability for meta-analysis.

The only outcomes presented across all studies were cover/frequency/occupancy of ericoid dwarf shrubs and graminoids. Ratios of graminoid:ericoid abundance were used to derive a standardised risk ratio metric, either by comparing before and after data or treatment control data. Data were imputed (Barker et al. 2004, Brian et al. 1976, Britton et al 2000a,b, Lippe et al.1985) where zero cells were encountered by adding one to each cell in the matrix (Pietrantonj 2006). Data from Hallam & Hallam (1981) displayed negative rates of change which were readjusted to plus one. Data from Vandvik et al. (2005) were extracted from online supplementary material that presented aggregated occupancy for grazed and ungrazed sites across years. Multiple points were extracted from single studies where risk ratios could be derived independently for different treatments and/or vegetation types.

3.7 Data synthesis

Data were insufficiently reported, interventions were too varied and sample sizes too small for meaningful meta-analysis pertaining to most of the primary outcomes (Table 1). However, a *post hoc* analysis was possible examining the ratios of graminoid: ericoid dwarf shrub cover. This exploratory analysis was intended to test the following hypotheses:

1) Grazing, burning and cutting result in higher ratios of graminoid:ericoid cover than no management

2) There is no difference in the ratio of graminoid: ericoid cover resulting from grazing, burning or cutting.
3) Temporal recovery and age of the dwarf-shrub heath do not influence the ratio of grass:ericoid cover.

Risk ratios (defining graminoid cover as the "detrimental" event) and pooled treatment effects across studies were generated, calculating weighted average risk ratios in random effect models using the method of DerSimonian & Laird, with the estimate of heterogeneity being taken from the Mantel-Haenszel model. Risk ratios compare the risk of having an event (graminoid cover) between two groups, namely management and no management, or before and after management. If an intervention (heathland management) has an identical effect to the control (no management), the risk ratio will be 1. If the chance of an effect is reduced by the intervention, the risk ratio will be less than 1; if it increases the chance of having the event, the risk ratio will be larger than 1. Therefore, a risk ratio of greater than one means that graminoid: ericoid cover is higher as a result of management. The presence of publication bias was investigated by means of a funnel plot (Sterne 2001) including a formal test of funnel plot asymmetry (Egger et al. 1997). We investigated heterogeneity using chi-squared tests, and carried out sensitivity analyses using odds ratios to investigate whether the choice of summary statistic is critical to the conclusions of the meta-analysis. The results of the meta-analysis were also re-expressed using risk difference as an absolute effect measure. Statistical analyses were performed using Stata 8.2 (StataCorp, College Station, Texas).

3.8 Evidence from literature excluded from the meta-analysis

Evidence was compiled from literature identified during the searches that met the criteria relating to subject, intervention and outcomes, but were excluded from the meta-analysis because of the lack of an appropriate comparator. To summarize the information presented, the text of each publication was read in its entirety, and used to assess the impact of grazing on heathland habitat attributes using a simple scoring approach. This was achieved using a three-point categorical scale, 'decrease', 'no change' or 'increase', referring to the impact of grazing on each individual attribute. The assessment process was performed by a single individual.

Habitat attributes were identified from recent summaries of the key habitat features of heathland, including those provided by the Common Standards Monitoring (JNCC 2004), Bacon (1998), Lake et al. (2001) and Offer et al. (2003). These summaries provide information about the habitat requirements of species of conservation concern that are associated with heathland, including birds, reptiles, amphibians, invertebrates, vascular plants, lichens and bryophytes. A combined list of habitat attributes (Appendix 2) was produced by integrating information from these different sources.

4. RESULTS

4.1 Review statistics

Of 3431 potentially relevant articles in bibliographic databases retrieved by electronic searching,, only 92 (<3%) were found to be relevant to management of lowland heath. Web searching and manual checking of bibliographies identified an additional 177 articles. Three references were unobtainable within the timeframe of the project (Appendix 1). This provided a total of 266 relevant articles. Only 13 of these had comparators; three examined the impacts of burning, three examined vegetation cutting, four examined grazing, and a further three examined the impacts of grazing, burning or cutting in combination. Of the remainder, 144 were considered as relevant to the review objectives following examination of each individual manuscript. These were subjected to a qualitative scoring procedure to extract further evidence regarding the impacts of grazing on lowland heathland.

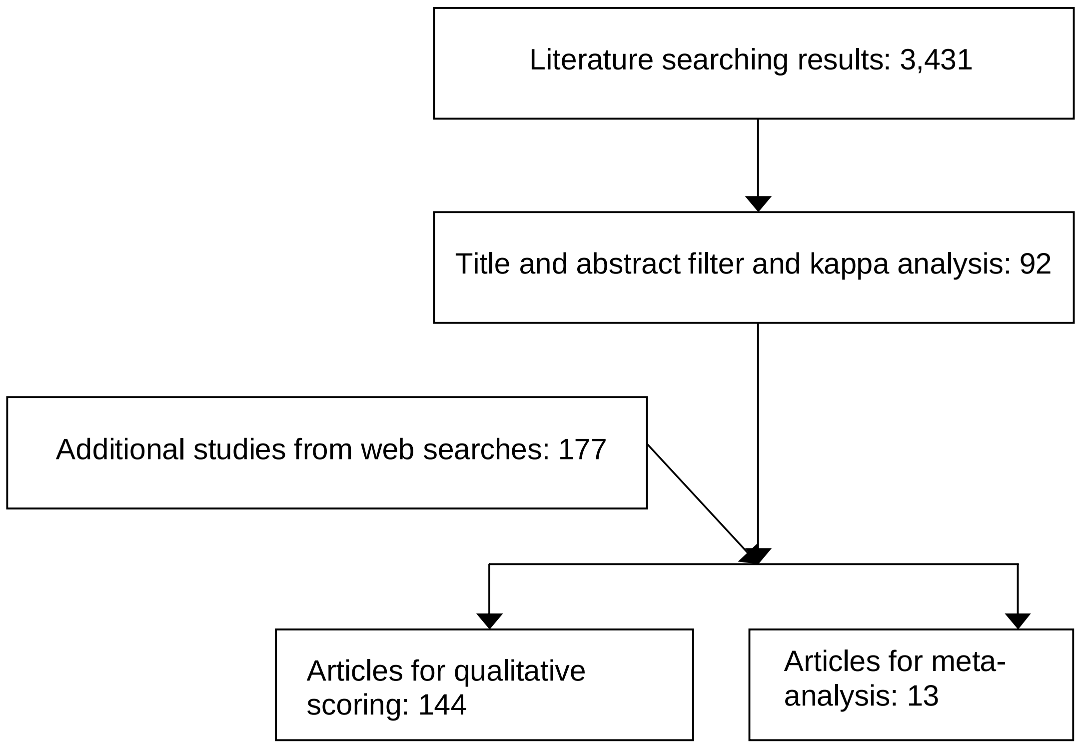

Figure 1: Numbers of articles at each stage of the process mapped onto the decision tree.

4.2 Study quality assessment

Insufficient data points exist for sensitivity analyses to investigate the impact of variation in study quality on meta-analytical results, therefore study characteristics were summarised qualitatively (Table 2). A diverse range of methodologies were employed by the limited number of studies with comparators (Table 2). Bias associated with the more reductionist studies mostly centres on the use of short timescales and low replication whereas longer-term monitoring studies do not generally possess appropriate controls (Table 2).

Table 2: Habitat type, experimental designs, interventions, comparators, replication, parameters of abundance and sources of bias of studies included in meta-analysis.

Reference	Habitat & Experimental design	Interventions & Comparators	replication	parameters of abundance	Sources of bias
Barker et al. (2004)	Randomized controlled trial with four replicate blocks. four management treatments were applied with and without nitrogen addition to H2 monoculture	Before and after management Long cut, short cut, intense simulated burn, management burn	n=4	Percentage of *Calluna vulgaris* cover, mean seedling number and biomass for litter production. Data were not presented regarding graminoid cover at the start of the experiment (assumed to be 1%).	Replication is low. Spatial and temporal scales are small but the experimental design minimises bias. Unfortunately rates of change have not been presented but experimental bias should be low. Insufficient information is included to assess the accuracy of abundance measures.
Bokdam & Gleichman (2000)	6 vegetation types (pioneer *Calluna* turf stripped 3 years prior to start of grazing, pioneer *Calluna* mown 1 year prior to start of grazing, mature *Calluna*, *Deschampsia* tussocks on podzols, *Deschampsia* tussocks on plaggen, *Molinia* tussocks on peat) monitored over 10 years, two of which had grazing exclosures to compare cattle (grazed versus ungrazed treatments)	Before and after management Grazing from 1983 to 1993 by 17 Dutch Fresian heifers then replaced by various breeds of suckling cows (0.2 animal units ha (1 unit =450kg) annual average-30% higher in summer). 3 horses also present on site. (supplementary food was provided in late winter 1-2kg animal per day).	n varies from 2 to 7 for the different vegetation types.	Percentage cover of ericaceous shrubs and graminoids	(Pseudo)replication is very low (and some plots were excluded because of heather beetle attacks). Changes in vegetation may not therefore all be attributable to the management regime. The different vegetation types are not independent as stock moved freely across the site and horses were also sometimes present on the cattle grazed treatment.
Brian et al. (1976)	Monitoring post burn recovery 12 years after a severe accidental burn on unspecified *Calluna*-dominated heath with some *Ulex* (H4?)	Before and after management Post burn monitoring after severe accidental 'razing' burn	n=157	A study specific measure of occupancy based on the number of parts out of eight occupied by ericoid and graminoid species	This study uses a robust measure of abundance but changes in vegetation could relate to many variables (pseudoreplication) and there is little information on the exact community types sampled or the previous management.
Britton et al. (2000a, b)	Randomized controlled trial with a split plot design and three blocks	Before and after management	n = 3 (5 for Knettishall heath)	Study specific measures of occupancy	Replication and timescale (27 months) are low but the robust

	incorporating three sites, vegetation type differences with three treatments, different gap sizes and seed addition in fully factorial combinations; vegetation types dry *Calluna* heath, *Deschampsia*-dominated heath and *Calluna-Deschampsia* heath (Knettishall).	Cutting (rotavating and turf stripping out-with relevant interventions)		based on subdivided cells	experimental design and parameter of abundance minimise bias
Bullock & Webb (1995)	Monitoring post burn recovery 11 years after fire at 11 heathland sites amalgamated into dry and humid heath	Replicated site comparison (burnt: unburnt)	n=11	Percentage frequency of graminoids and ericoids	The data are effectively a replicated site comparison with no time element. Variation in initial composition could therefore confound the results
Bullock & Pakeman (1996)	A series of site comparisons within and between sites with different management histories and vegetation types amalgamated Only data concerning grazing in humid and dry heath had appropriate comparators	Site comparison (grazed:ungrazed)	n varies from 5 to 15 for the different vegetation types.	Percentage cover assessed by eye	There is considerable potential for bias arising from this multisite comparison owing to potential changes occuring concurrent with management. Additionally, not all vegetation types are independent, (pseudo)replication was low and abundance was assessed by eye.
Clarke (1988)	Site comparisons comparing grazed and ungrazed (or differential grazing intensities) sites at two locations	Site comparison (grazed:ungrazed) stock type and intensity unknown	Unspecified number of pseudoreplicated samples taken at each site	Percentage cover assessed by eye (some biomass data are also presented)	This was corollary information from a thesis. There is considerable potential for bias owing to confounded baselines and estimation of cover, worsened by lack of reporting detail in methods.
Froment (1981)	Before and after comparisons examining the impact of cutting (with and without litter removal), burning and "ecobuage" or burn-beating which consists of sod cutting, drying the sods and buring them in order to use the ash	Before and after management Cut with litter removed, cut with litter left, burn.	Unspecified number of pseudoreplicated permanent quadrats. n=1 for genuine replication	Percentage cover assessed by eye (method assumed)	Experimental design is poor with the potential for other factors to account for change. No controls, replication and parameter estimation not fully elucidated in methods, therefore considerable potential for bias

	as fertilizer for a rye crop. Only the burning and cutting treatments were considered				
Gallet & Roze, (2001)	Monitoring in five paddocks under different sheep grazing regimes over two years in dry heath and mesophilous heath.	Before and after management Grazing dry heath ('landes de bretagne', sheep at 0.55LUha continuous grazing, at 1.71LUha summer only, at 1.33LUha winter only) and mesophilous heath (sheep at 1.71LUha spring and summer grazing, sheep at 1.71LUha summer only)	Unclear but n=1 for genuine replication of treatment-vegetation type	Frequency assessed using point quadrats on transects expressed as percentages	The potential for bias is large given the short timescale and pseudoreplication. Additionally, there is internal confounding as variation in grazing intensity confounds differences owing to timing of grazing.
Hallam & Hallam (1981)	The paper reports two burning trials, sod cutting and cutting twice per year. Comparators are not presented for the burnt plots and the sod cutting is not relevant to this review, but the cutting experiment was extracted	BACI design for the cutting twice per annum Change over time in treatment compared to control	Unspecificed number of pseudoreplicated occupancy measures recorded every year for five years	Occupancy in 20 cm frame repeated across diagonals of 5 m*3 m exclosures	The lack of genuine replication introduces the potential for low external validity but treatment-control monitored over time yields robust data especially when coupled with the objective parameter of abundance
Lippe, et al (1985)	Permanent quadrats monitored annually for 17 years on *Calluna Empetrum* heath (*Genisto-callunetum* association).	Before and after management Post burn succession with sheep grazing at unspecified intensity	n= 1025 (pseudoreplicated pins recorded each year)	Pin hits from a permanent quadrat	Lack of a control and replication are the primary sources of bias.
Vandvik et al (2005)	Controlled trial with twelve experimental blocks spanning three vegetation types (dry, intermediate, and moist heath) and two management interventions (burnt then no grazing v burnt and grazed)	Treatment control percent occurrence across all years. Burnt and grazed by sheep at 0.16LUha or 5 years compared to burnt and ungrazed vegetation.	n=2	Occupancy of cells in permanent quadrats	Robust experimental design and use of objective parameter of abundance limit bias although replication is low

4.3 Meta-analysis

The risk ratios of graminoid:ericoid covers are variable, and 20 of 31 are not significant (Figure 2). The pooled risk ratio is 1.19 (95% CI 1.07 - 1.33, test of RR=1: z= 3.18 $p < 0.001$) indicating an overall increase in graminoids relative to ericoids confirming hypothesis one, that management interventions (grazing, curtting or burning) result in higher ratios of graminoid:ericoid cover than no management. However, there is significant heterogeneity between studies (heterogeneity chi-squared = 302.91 (d.f. = 30) $p < 0.001$).

The pooled odds ratio (that compares how likely an event is between two groups) and risk difference (that compares the risk in terms of an absolute difference rather than in relative terms) are both positive (but statistically non-significant). Significant variation was recorded between individual data points, suggesting that choice of analytical method is not critical in terms of effect although it does alter the degree of statistical significance. There is no evidence of funnel plot asymmetry, hence publication bias, despite the comparative lack of "grey literature" included in the meta-analysis (Egger: bias = 0.335, p= 0.553, Figure 3). Subgroup analyses were undertaken to investigate if heterogeneity could be explained by variation in treatment (hypothesis two).

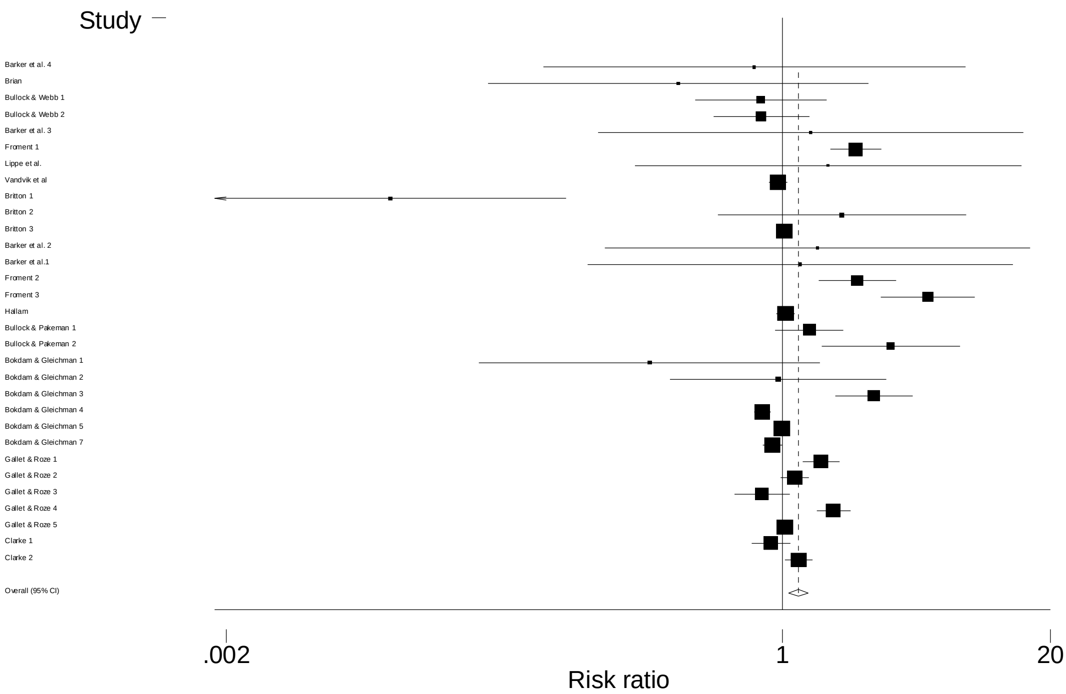

Figure 2: Forrest plot of graminoid:ericoid risk ratios. Solid boxes represent the individual risk ratios; box size is related to event rate; error bars are 95% confidence intervals; the open diamond is the pooled effect size generated using random effects meta-analysis.

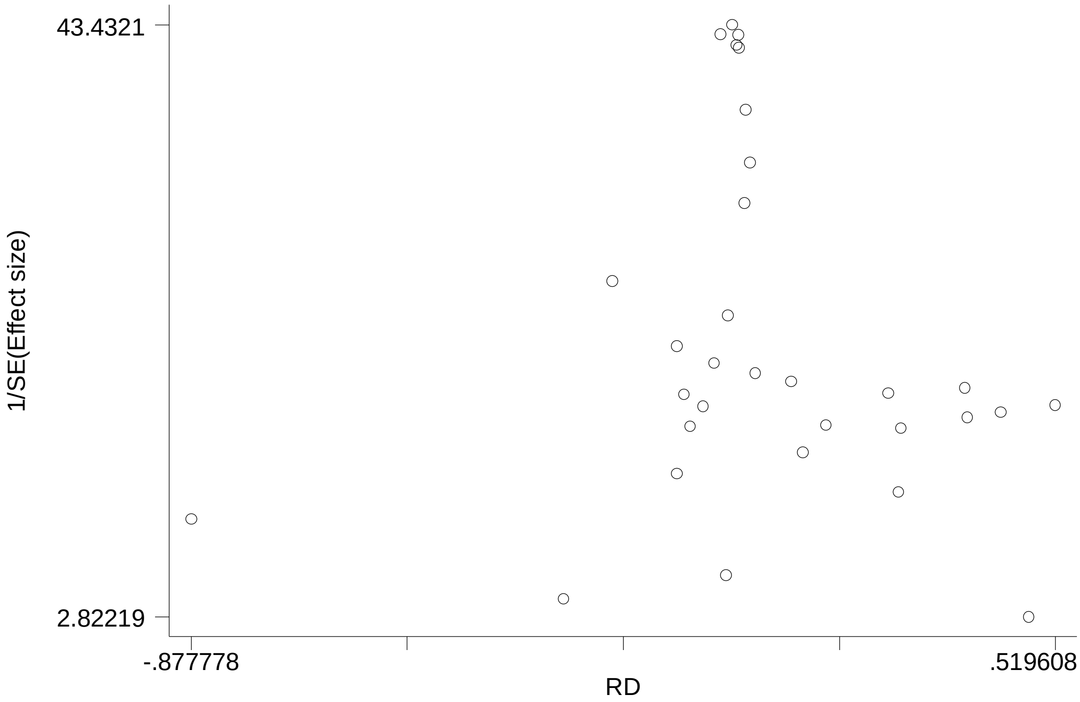

Figure 3: Funnel plot to assess evidence of publication bias. The x axis provides magnitudes of effect measured as risk difference for each data point in the meta-analysis; the y axis is the inverse variance of the effect sizes. The plot illustrates that there are more small positive studies than small negative studies, but small negative studies are represented.

The pooled risk ratios (RR) for burning and cutting were both >1, suggesting an increase in the ratio of graminoids to ericoids, but neither was statistically significant (pooled RR burning = 1.07, test of RR=1 : z= 0.3 p = 0.77, n=8 ; pooled RR cutting = 1.34, test of RR=1 : z= 1.12 p = 0.26, n=8). There was significant heterogeneity between the studies for both burning and cutting (burning heterogeneity chi-squared = 34.76, d.f. = 4, p =<0.001; cutting heterogeneity chi-squared = 211.3, d.f. = 4, p =<0.001), but the small sample sizes precluded further investigation of the reasons for this variation.

The pooled risk ratio for grazed sites was also >1 but in this case was statistically significant indicating that grazing increases the ratio of graminoids to ericoids (pooled RR 1.16, test of RR=1 : z= 2.03 p = 0.042, Figure 4). There is significant variation between the studies (heterogeneity chi-squared = 185.33, d.f. = 14, p < 0.001) which could be due to a myriad of factors (Table 2). With respect to hypothesis 2, only grazing was found to significantly increase the overall ratio of graminoids to ericoids.

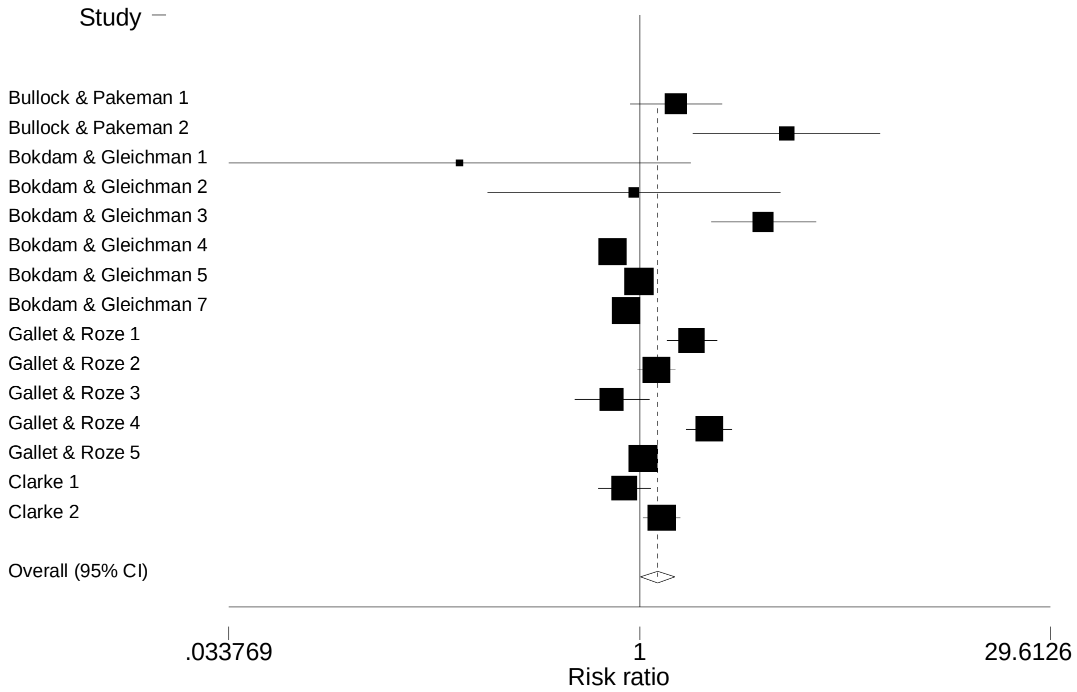

Figure 4: Forrest plot of graminoid:ericoid risk ratios for grazed sites. Solid boxes represent the individual risk ratios; box size is related to event rate; error bars are 95% confidence intervals; the open diamond is the pooled effect size generated using random effects meta-analysis.

We investigated the effect of time on the impact of grazing management using meta-regression, but this was not significant ($\alpha < 0.05$, coefficient -0.001, z= -1.03, p= 0.304). Stock type does not appear to have a consistent impact on the effect size (Table 2, Figure 4) but this was not investigated quantitatively owing to small sample sizes. Insufficient data precluded analysis of the impact of age of *Calluna vulgaris* or reasons for heterogeneity in the cutting or burning treatments. Thus, with respect to hypothesis three, there is significant variation in the impact of grazing but no reasons for this variation have been identified.

4.3 Outcome of the review

Experimental and management methodologies were too diverse for meta-analysis, and sample size was insufficient for robust multivariate analysis of data regarding most of the effects of heathland management on the changes in species composition identified as important by stakeholder groups outlined in Table 1.

However, there was sufficient standardised reporting of changes in ericoid and graminoid abundance to derive and meta-analyse risk ratio effect metrics. Statistically, grazing had a significant effect on the ratio of graminoid:ericoid cover, in that values associated with grazing were significantly different from zero. However, there was no statistical difference between the effects of grazing, burning and cutting. This suggests that grazing is appropriate for maintaining plagioclimax heathland vegetation. However, there is considerable unexplained variation in the results, particularly for burning and cutting, which are based on a small number of studies with considerable potential for bias (Table 2).

Variation in the intensity and timing of grazing and vegetation type clearly have an impact as illustrated by the Gallet & Roze, (2001) data points (Table 2, Figure 4). Samples sizes are insufficient to explore the impact of these factors. Likewise, variation in experimental methodologies could account for variation in results but could not be analysed. Thus, although there is a statistically significant difference between grazing and burning or cutting, considerable uncertainty remains regarding its biological significance.

4.4 Assessment of literature excluded from the meta-analysis

In general, information for most attributes was lacking in this literature, and in many cases, it was difficult to ascribe any impacts specifically to grazing. While in some cases statements regarding such impacts were supported by monitoring or survey data, in many cases, no such supporting information was provided. Overall, the majority of studies suggested that grazing increases the amount of bare ground, the spatial heterogeneity of ericaceous shrubs, the cover of grass species, the cover of forbs, the cover of bryophytes, the quality of pond margins, the amount of animal dung and the occurrence of disturbance indicators (Table 3). Conversely, the majority of studies indicated that grazing decreases the percentage cover and height of ericaceous shrubs, the cover and average height of gorse, the mean height of grasses and the abundance of grass tussocks, the cover of bracken and the abundance of tree and shrub saplings (Table 3) for species such as oak, birch and alder buckthorn (Table 6b). For other habitat attributes, evidence was either lacking or equivocal.

Table 3. Impacts of grazing on habitat attributes of lowland heathland, assessed by scoring literature that did not meet the systematic review criteria (see text for details). Values are percentages; number of studies in parentheses. – indicates decrease, + indicates an increase. 144 articles were assessed in total.

Habitat attribute	**-**	**No change**	**+**
Amount of bare ground (1)			100
Percentage cover of all ericaceous shrubs (19)	89		11
Percentage cover of *mature* ericaceous shrubs (0)			
Percentage cover of *juvenile* ericaceous shrubs (0)			
Average height of ericaceous shrubs (8)	74	13	13
Spatial heterogeneity of ericaceous shrubs (1)			100
Cover of gorse (6)	100		
Average height of gorse (2)	100		
Cover of grass species (14)	14		86
Mean height of grass species (5)	100		
Abundance of grass tussocks (11)	100		
Cover of forbs (7)	14		86
Cover of bryophytes (5)	20		80
Cover of lichens (2)	50		50
Cover of *Rhododendron* (0)			
Cover of bracken (3)	66	33	
Abundance of tree and shrub saplings (9)	89	11	
Amount of accumulated decomposing vegetation or leaf litter (2)	50		50
Quality of pond margins (1)			100
Number of ponds or pools (0)			
Amount of animal dung (3)			100
Presence of overgrazing indicators (eg trampling of vegetation or formation of animal tracks) (1)			100
Presence of other disturbances (eg habitat erosion, fires, or use by dog walkers) (0)			

4.4 **Results of questionnaire survey**

In total, responses were received from 53 heathland managers, representing 67 heathland sites. Heathland sites were distributed throughout England and Wales, with a single site in Scotland (Figure 5), and ranged from 2-13,000 ha in area.On seven sites, grazing has a long and continuous history. On all of the other sites, grazing has been (re)introduced relatively recently, with a mean of ten years since reintroduction. On most of these sites (90% of those for which historical information is available), grazing was practiced historically, but ceased at some point. Most commonly, grazing ceased in the 1930's (five heaths) or 1940s (four heaths).

Other management techniques have frequently been used in conjunction with grazing, including use of fire (recorded on 38% of heaths, including accidental fires and arson; fire currently used as a formal management intervention on 17% of sites), cutting

(66%), herbicides (30%). On those sites where cutting takes place, it is usually undertaken on a limited scale (i.e. <5% of the area of the site cut annually; or restricted to clearance of firebreaks). Only four respondents reported extensive use (i.e. over > 10% of area annually) of cutting or mowing. Other techniques used on a minority of sites (<30%) included soil stripping, rotovating, litter or soil scraping, reseeding with heather, rolling, harrowing and mulching.

Prior to the reintroduction of grazing, colonization by shrubs and trees was considered to be a major problem on 60% of sites, a minor problem on 25% and not a problem on 15% of sites. The opinions of the respondents were informed by the results of formal monitoring (using permanent sample plots) in 30% of cases; in all other cases, opinions were based on the informal observations of the respondents, often supplemented by other monitoring approaches (such as fixed point photography, field surveys and opinions of others). Cows are most commonly used as grazing animals, reported on 66% of sites, with ponies and sheep reported on 47% and 34% of sites respectively. Other animals were reported on 15% of sites, and included donkeys, deer and goats. Stocking density typically varies both seasonally and annually, in response to the perceived needs of the site.

Overall, a mean livestock density of 0.88 animals ha^{-1} was reported, with values ranging from 0.05-4 animals ha^{-1}. Most commonly (75% of sites), animals are of mixed gender, but on 18% only female animals are used and on 6% all animals are male. In terms of age, most sites (82%) employ both juvenile and mature animals, but on 14% sites only mature animals are used and on 4% only juveniles. Grazing is carried out throughout the year on 36% of sites, and primarily during the summer on 49% of sites. On 83% of sites, animals were reported to concentrate their activity in preferred grazing zones, whereas even grazing throughout the site was only reported in 17% of sites. Use of mineral licks was reported on 40% of sites, and supplementary feeding is provided on 19% of sites, primarily in the winter. Use of Avermectins was reported on 17% of sites.

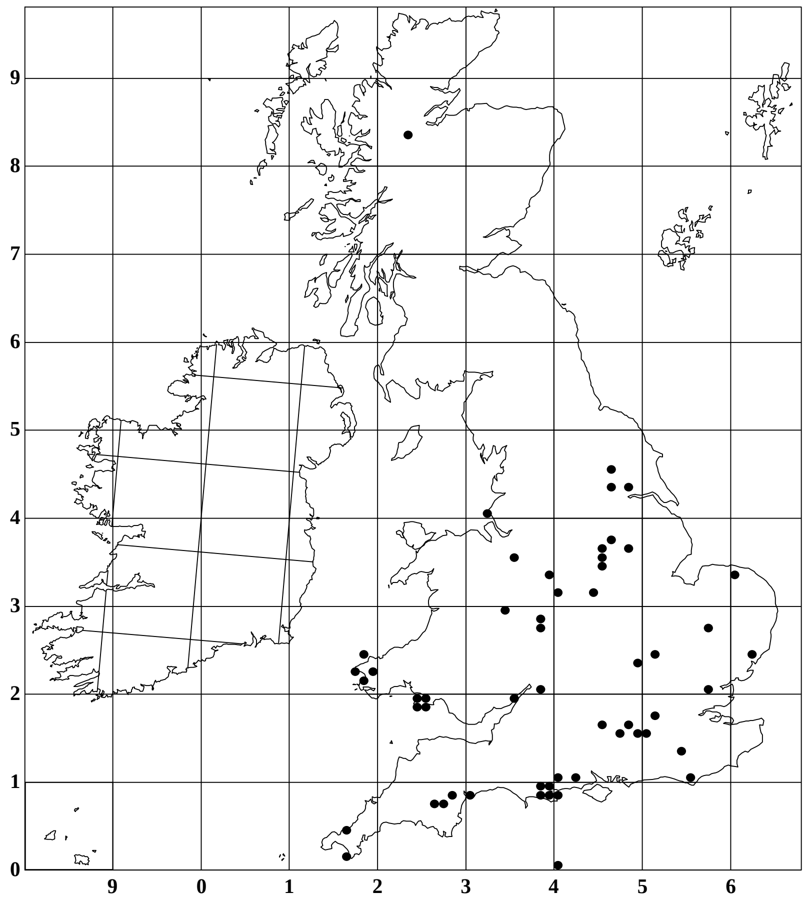

Figure 5. Distribution of heathland sites included in questionnaire survey.

Effectiveness of grazing as a management approach

A large majority of respondents (94%) believe that grazing has been effective in meeting at least one management objective; in only 6% of cases has grazing failed to be effective in meeting any management objective. The most common management objectives were suppression of scrub vegetation (including tree colonization); grazing was found to be effective in 82% of cases where this was stated as an objective (Table 4). The other two most widespread objectives were (i) reduction of tussocky or coarse grasses (including *Molinia* and *Deschampsia*), where grazing was found to be effective in 75% of cases, and (ii) improvement of vegetation structure (principally of heather, but also other ericaceous plants), where grazing was found to be effective in 93% of cases where this was included as a management objective (Table 4).

Table 4. Summary of questionnaire responses, relating to the effectiveness of grazing in addressing a range of management interventions listed by respondents. (Numbers refer to the number of respondents).

Management intervention	**Effective**	**Not effective**
Suppression of scrub vegetation	28	6
Reduction of dominance of tussocky or coarse grasses	15	5
Creation of areas of bare ground	3	2
Improvement of vegetation structure (particularly heather)	13	1
Control of bracken	4	4
Create dung habitat	3	
Increase heather cover	1	1
Maintain or improve habitat mosaic / habitat diversity	8	
Reduce spread of invasive plant species	3	
Increase public interest and involvement	3	
Improve pond management	2	
Improve bird habitat	1	
Act as seed vectors		1
Maintain populations of notable vascular plants		1

Impacts of grazing

A total of 40 respondents commented on the impacts of grazing on the spatial structure of ericaceous shrubs. Of these, 38% reported that spatial structure was less homogeneous as a result of grazing, with 15% reporting the converse. The remainder of respondents reported no change.

Other key features of the results (see Tables 5 and 6) were that:

- A majority of respondents (>50%) reported that grazing leads to an *increase* in the amount of bare ground, percentage cover of all ericaceous shrubs, percentage cover of juveniles ericaceous shrubs, the quality of pond margins, the amount of animal dung, and the presence of overgrazing indicators
- A majority of respondents (>50%) reported that grazing leads to a *decrease* in the mean height of grass species, the abundance of grass tussocks, and the abundance of tree and shrub saplings.
- A majority of respondents reported that grazing reduces the abundance of saplings of oak, pine, birch and willow. In only one species (alder buckthorn) did a majority of respondents report an increase in sapling abundance following the introduction of grazing (Table 6).

Table 5. Impacts of grazing on a range of habitat characteristics. Values refer to the percentage of respondents; number of respondents in parentheses.

Habitat characteristic	**Large decrease**	**Small decrease**	**No change**	**Small increase**	**Large increase**
Amount of bare ground (48)	4	8	33	42	13
Percentage cover of all ericaceous shrubs (46)	0	13	33	43	11
Percentage cover of *mature* ericaceous shrubs (45)	4	27	64	4	0
Percentage cover of *juvenile* ericaceous shrubs (44)	2	5	39	34	20
Average height of ericaceous shrubs (45)	13	24	47	16	0
Cover of gorse (42)	10	24	38	21	7
Mean height of gorse (40)	8	20	58	13	3
Cover of grass species (44)	2	27	48	18	5
Mean height of grass species (46)	43	41	11	4	0
Abundance of grass tussocks (44)	23	32	36	9	0
Cover of forbs (34)	0	15	44	41	0
Cover of bryophytes (35)	0	6	74	17	3
Cover of lichens (34)	0	3	71	24	3
Cover of *Rhododendron (20)*	30	5	55	10	0
Cover of bracken (38)	18	24	47	8	3
Abundance of tree and shrub saplings (45)	18	36	27	11	9
Amount of accumulated decomposing vegetation or leaf litter (36)	19	28	47	6	0
Quality of pond margins (28)	4	18	25	32	21
Number of ponds or pools (37)	0	3	78	14	5
Amount of animal dung (48)	0	6	4	33	56
Presence of overgrazing indicators (eg trampling of vegetation or formation of animal tracks) (47)	4	0	23	55	17
Presence of other disturbances (eg habitat erosion, fires, or use by dog walkers) (46)	4	24	46	20	7

Table 6. Impacts of grazing on abundance of saplings of individual tree species, based on: (a) questionnaire responses, where values refer to the percentage of respondents, with the number of respondents in parentheses; (b) scoring of literature that did not meet the selection criteria for the meta-analysis.

(a)

Species	**Large decrease**	**Small decrease**	**No change**	**Small increase**	**Large increase**
Oak (11)	18	64	18	0	0
Pine (16)	19	38	31	13	0
Birch (29)	28	28	17	14	14
Rowan (6)	17	33	0	33	17
Hawthorn (4)	0	25	50	25	0
Alder buckthorn (1)	0	0	0	100	0
Willow (11)	9	73	18	0	0
Aspen (1)	0	0	100	0	0

(b)

Species	**Large decrease**	**Small decrease**	**No change**	**Small increase**	**Large increase**
Oak (4)	0	75	0	0	25
Pine (6)	0	33	66	0	0
Birch (6)	17	49	17	0	17
Rowan (2)	0	50	0	50	0
Hawthorn (0)	-	-	-	-	-
Alder buckthorn (4)	25	50	0	25	0
Willow (2)	100	0	0	0	0
Aspen (1)	0	100	0	0	0

Summary of questionnaire results

Generally, the vast majority of heathland managers believe that the introduction of grazing has helped meet management objectives, particularly the suppression of scrub vegetation (including tree colonization), reduction of tussocky or coarse grasses and improvement of vegetation structure. In addition, managers provided evidence regarding a wide range of individual impacts of grazing on heathland habitats, including widespread reports of an *increase* in the amount of bare ground, percentage cover of all ericaceous shrubs, percentage cover of juveniles ericaceous shrubs, the quality of pond margins, the amount of animal dung, and the presence of overgrazing indicators; and a widespread *decrease* in the mean height of grass species, the abundance of grass tussocks, and the abundance of tree and shrub saplings. Interestingly, the main result of the meta-analysis (an increase in the cover of grassland compared to ericaceous shrubs) was not reported by the majority of respondents. This highlights an apparent difference between these lines of evidence. The impacts of grazing vary substantially from site to site, which may be attributed to variation in a wide range of factors including stocking density, livestock type, vegetation characteristics, soil type, etc. Such variation limits the potential for identifying generalizations regarding the impact of grazing. Furthermore, no attempt was made here to compare the impacts of grazing versus other management interventions, such as burning or cutting. In general (i.e. on 75% of heaths) grazing is used in conjunction with burning and / or cutting, rather than as an alternative to these management interventions.

5. DISCUSSION

5.1 Evidence of effect

Statistically, there is evidence that grazing increases the ratio of graminoids to ericoids. In the case of burning and cutting, no such effects were evident, but this may simply reflect a lack of statistical power in relation to these interventions. The study responses vary considerably and there are many factors which could contribute to these differences, such as grazing intensity, timing, stock type, initial floristic composition and the experimental methodologies of the studies. The impact of grazing cannot be ascertained with any certainty without evidence regarding these factors. Whilst statistically significant, the magnitude of the effect is small, and it was derived from a *post hoc* subgroup analysis. Additional caution is therefore required when interpreting the biological significance of this result.

5.2 Review limitations

A large proportion of the literature accepted for full text assessment comprised review and discussion articles providing little primary data. Many included studies presented no baseline or control data. Even where such data exist, variance measures were often absent or unreported. In some instances further data may be obtainable from the authors, but resource limitations precluded pursuing all authors who may have held data. Whilst additional data may have increased the quality of the analysis it is probable that small sample size relative to the number of confounding variables would remain the primary limitation of the review.

The altitudinal division between upland and lowland is rather arbitrary. Meta-analysts must beware of combining “apples and oranges” as this can result in high heterogeneity making pooled effect sizes difficult to interpret. We chose an altitude of 200 m to exclude upland vegetation such as the heathland on Bodmin Moor and the fringes of Dartmoor, Southern England. This increases the external validity of the results and minimises the already high heterogeneity but it may distort the sampling universe as some vegetation that may be considered lowland is excluded; e.g. the “Muir of Dinnet”, Scotland, which has been the focus of much heathland research.

5.3 Uses of other sources of evidence

An increase in graminoids relative to ericoids as a result of grazing is consistent with the findings of a conventional literature review (Lake et al. 2001), and has also been widely reported from upland moor vegetation. The same result was found in the analysis of literature excluded from the meta-analysis, where a large majority of studies reported both an increase in grass cover and a decrease in cover of ericaceous shrubs. Surprisingly, however, the same result was not obtained by the questionnaire survey. A majority of respondents (54%) reported an increase in cover of ericaceous shrubs resulting from grazing, whereas a higher percentage of practitioners reported a decline in grass cover (29%) than reported an increase (23%). This therefore represents a conflict between different sources of evidence: results from the questionnaire survey directly contradict the only statistically significant result of the meta-analysis.

Some conflicts between scientific evidence and conservation practice have been reported previously; indeed, this is one of the main justifications given for an evidence-based approach to conservation. Are the opinions of heathland managers therefore out of step with scientific evidence? In fact, when the questionnaire responses are compared with the literature that was scored, there is generally a close correspondence between these two types of evidence. For example, a higher percentage of managers considered that grazing results in an increase in bare ground than in a decrease, in line with the scored literature. Such agreements were recorded in 14 of the variables assessed, and disagreements in only four (lichen cover, accumulated leaf litter, cover of ericaceous shrubs and grass cover). This suggests there is some consensus between the opinions of managers and the scientific literature with respect to grazing impacts such as the reduction in grass tussocks, control of scrub development and improvement of pond margins.

Results of this investigation therefore indicate that a variety of different forms of evidence can usefully inform a systematic review. Inclusion of different forms of expert opinion, as well as meta-analysis of research results, enables both the breadth of outcomes and the sample size to be increased, providing a more comprehensive assessment of the potential impacts of management interventions. However, caution should clearly be exercised when integrating different sources of evidence, because of the risk of obscuring knowledge gaps with evidence of insufficient rigour. Comparison of different sources of evidence can help identify conflicts, which may be useful in identifying knowledge gaps, but present a challenge to data analysis and the formulation of management recommendations. In the current investigation, the conflict between the results of meta-analysis and expert opinion suggests a bias in the latter. Conversion of ericaceous shrub cover to grassland is a potentially negative outcome in terms of heathland management, which some managers might be reluctant to identify. Conflicts such as this highlight the need for improved monitoring information to objectively verify the impacts of management.

6. REVIEWERS' CONCLUSIONS

6.1 Implications for conservation management

Available evidence based on results of a meta-analysis suggests that grazing can increase the ratio of graminoids to ericoids on heathlands. However, there is very little evidence available on the relative impacts of burning, grazing and cutting on lowland heath. Monitoring the impacts of interventions before and after implementation and further experimentation are necessary in order to develop a robust evidence base regarding the relative impacts of these interventions.

Results also show that use of additional sources of evidence, such as expert opinion, can usefully contribute to the systematic review process. This form of evidence suggests that grazing impacts can clearly be negative on some habitat features. For example, both sources of expert opinion were consistent in reporting declines in the vertical structure of ericaceous shrubs, gorse cover and abundance of grass tussocks, which are likely to be deleterious to reptiles. Similarly, the reported declines in the abundance of tree species, cover of ericaceous shrubs and abundance of grass tussocks are likely to have negative impacts on invertebrate communities. Reported declines in gorse cover and vertical structure are likely to have negative impacts on some bird species, such as Dartford warbler and linnet (Lake et al. 2001). Reviews of information in relation to key habitat attributes, as performed here, can help identify such negative impacts, which should clearly be carefully monitored. Not all important habitat features, such as gorse vertical structure and grass tussocks, are currently incorporated in standard monitoring approaches (JNCC 2004).

6.2 Implications for further research

Further research regarding the effects of heathland management is urgently required if a robust evidence-base is desired. Studies should include comparator(s) and baselines wherever possible. Replication should be accorded higher value than has been traditional as 70% of existing 'high' quality information lacks statistical significance owing to large variance and small sample sizes.

Experimental studies should consider adequately powered sampling of parameters that are currently incorporated in standard monitoring approaches (JNCC, 2004). It is worth noting that not all important habitat features, such as gorse vertical structure and occurrence of grass tussocks are covered by the JNCC standard approach, so additional parameters may require estimation depending on the precise objectives of the study.

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8. POTENTIAL CONFLICTS OF INTEREST AND SOURCES OF SUPPORT

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Appendix 1: Unobtained material

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Appendix 2. Attributes of heathlands assessed in the questionnaire survey. From JNCC (2004), Bacon (1998), Lake et al. (2001) and Offer et al. (2003). Numbers refer to number of respondents for each attribute in the questionnaire survey.

Habitat characteristic
Amount of bare ground
Percentage cover of all ericaceous shrubs
Percentage cover of *mature* ericaceous shrubs
Percentage cover of *juvenile* ericaceous shrubs
Average height of ericaceous shrubs
Spatial heterogeneity of ericaceous shrubs
Cover of gorse
Mean height of gorse
Cover of grass species
Mean height of grass species
Abundance of grass tussocks
Cover of forbs
Cover of bryophytes
Cover of lichens
Cover of *Rhododendron*
Cover of bracken
Abundance of tree and shrub saplings
Amount of accumulated decomposing vegetation or leaf litter
Quality of pond margins
Number of ponds or pools
Amount of animal dung
Presence of overgrazing indicators (eg trampling of vegetation or formation of animal tracks)
Presence of other disturbances (eg habitat erosion, fires, or use by dog walkers)