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DOES BURNING DEGRADE BLANKET BOG?

Systematic Review

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CENTRE FOR EVIDENCE-BASED CONSERVATION

Systematic Review No. 1

Does Burning Degrade Blanket Bog?

Review Report

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SUMMARY

Background
Burning has a significant impact on the floristic composition of many areas in upland UK. Blanket bogs are one of the upland communities of conservation concern. The effects of burning on blanket bog need to be reviewed systematically in order to determine whether or not burning is compatible with nature conservation objectives.

Objectives
To determine whether burning degrades blanket bog vegetation in Great Britain and Ireland.

Search Strategy
The following computerised English language databases were searched: English Nature's "Wildlink", JSTOR, ISI Web of Knowledge (comprising BIOSIS previews, CAB Abstracts, Derwent Innovations Index, INSPEC, ISI Current Contents, ISI Proceedings, ISI Web of Science), Index to Theses Online. Additionally, the reference lists of articles were searched and selected authors, recognised experts and current practitioners in the field of upland ecology were contacted for further references.

Selection Criteria
Primary, quantitative studies of burning on blanket bog or wet heath in Great Britain and Ireland (NVC types: M1, M2, M3, M17, M18, M19, M20, M21 and on peat >50 cm deep, M15, M16, M25, U6) with appropriate controls or other unburnt comparators. The outcome was any change in floristic composition interpreted in the context of Common standard monitoring (CSM) favourable condition criteria.

Data collection and analysis
Inclusion decisions, quality assessment and data extraction were duplicated, and consensus achieved by discussion or a third party. Some authors were contacted for missing data. The primary measure of effect was favourable condition status derived from floristic composition data. Attempts at quantitative analysis using Random effects meta-analyses, Detrended Correspondence Analysis (DCA) and Canonical Correspondence Analysis (CCA) were severely constrained by the nature of the data, thus vote counting proved the most effective means of data synthesis.

Main Results
Eight articles were included. These reported the results of 11 independent datasets. Three datasets indicated that burning degraded blanket bog, five were contradictory and three indicated that burning did not degrade blanket bog. The evidence for degradation became stronger when randomized controlled trials were distinguished from site comparisons. However, these outcomes are dependent on interpreting changes in floristic composition in the context of favourable condition criteria. They are not robust to changes in favourable condition criteria and were subject to problems of scale, standardisation and repeatability.

Conclusions

The weight of available evidence suggests that burning either degrades blanket bog or is contradictory in effect. If quality of evidence is used to discriminate among studies then the evidence for degradation becomes stronger. However, a degree of circumspection is required given the small sample size, variable timescales of the studies and problems in the interpretation of favourable condition. Significantly, only one article (2 datasets) reported on the effects of rotational burning. It is clear that more high quality research and monitoring of burning on blanket bogs is required, in particular, long term studies that deal with more than one burning rotation. Pending further research it is suggested that burning on blanket bog and wet heath should normally be avoided if favourable condition is to be achieved or maintained.

Does Burning Degrade Blanket Bog?

1. Background

Burning has been an important management tool in the British uplands for centuries. Today, burning is generally undertaken either to promote the growth of young heather for grouse on sporting estates or to promote the growth of grass and young heather to provide forage for sheep (Tucker 2004). Dry dwarf shrub heath is often subjected to burning, particularly on grouse moors but wetter communities such as wet heath and blanket bog are also burnt. Burning in these communities may be accidental where they occur in mosaics with dry dwarf shrub heath or may be undertaken to promote graminoid growth for grazing stock (Shaw *et al.* 1996, Tucker 2004).

Burning can have a large impact on the floristic composition of both wet heath and blanket bog (Shaw *et al.* 1996, Tucker 2004). However, there is still debate over the optimal management for the conservation of the flora of blanket bog and wet heath and indeed, what the management requirements are (Shaw *et al.* 1996). A systematic review was commissioned to evaluate, synthesise and disseminate information concerning the effects of burning on wet heath and blanket bog.

2. Objective of the Review

To determine whether burning degrades blanket bog vegetation in Great Britain and Ireland.

3. Methods

3.1. Question Formulation

The issue was initially raised by the English Nature 'Uplands Group', part of the Terrestrial Wildlife Team and the specific review question was formulated following a meeting between this Team and CEBC personnel. The Question contains three elements, a subject, an intervention and a desired outcome, each of which is defined as follows:

Subjects(s)
Upland British and Irish blanket bog or wet heath. This includes the following National Vegetation Classification (NVC) types (Rodwell 1991): M1 *Sphagnum auriculatum* bog pool community, M2 *Sphagnum cuspidatum / recurvum* bog pool community, M3 *Eriophorum angustifolium* bog pool community, M17 *Scirpus cespitosus – Eriophorum vaginatum* blanket mire, M18 *Erica tetralix – Sphagnum papillosum* raised and blanket mire, M19 *Calluna vulgaris – Eriophorum vaginatum* blanket mire, M20 *Eriophorum vaginatum* blanket and raised mire, M21 *Narthecium ossifragum – Sphagnum papillosum* valley mire. Some of these NVC types occur on lowland raised bogs and in valley mires where they are not considered relevant. M15 *Scirpus cespitosus – Erica tetralix* wet heath, M16 *Erica tetralix – Sphagnum compactum* wet heath, M25 *Molinia caerulea – Potentilla erecta* mire, U6 *Juncus squarrosus – Festuca ovina* grassland

were also considered relevant as forms of degraded bog provided that they were on peat deeper than 0.5m or subject to impeded drainage with floristic affinity to bog communities. These NVC communities are of national and international importance as reflected by their inclusion in the EU Annex I priority habitat types list: Blanket bogs (H7130), Depressions on peat substrates of the Rhynchosporion (H7150).

Intervention

The study must have compared burning with no burning as a variable.

Outcome(s)

The effects of burning on the floristic composition of the subject must have been measured or monitored and be interpretable in the context of favourable condition criteria (Joint Nature Conservation Committee (JNCC), 2004) as blanket bog degradation was defined in terms of deviation from favourable condition.

3.2. Search Strategy

Studies, in the English language, were identified through computerised searches of English Nature's "Wildlink", JSTOR, ISI Web of Knowledge (comprising BIOSIS previews: 1969 to present, CAB Abstracts: 1973 to present, Derwent Innovations Index: 1963 to present, INSPEC: 1969 to present, ISI Current Contents: 1997 to present, ISI Proceedings: 1990 to present, ISI Web of Science: 1975 to present), Index to Theses Online (1970 to present). The search strategies used (Appendix 1) combined synonyms for moor burning with target habitat and species terms.

To enhance the search we provided 52 recognised experts and current practitioners in the field of upland ecology with the provisional short list of articles and asked them to list any they thought we had missed. We also searched the bibliographies of articles accepted for full text viewing and contacted authors of articles that did not present data that were inferred to exist from methodological descriptions, or that presented data that could not easily be extracted.

3.3. Study Inclusion Criteria

Two reviewers assessed articles for broad relevance by screening of title and abstract. Three reviewers subsequently studied the full texts of selected articles for relevance and admitted them to the review by consensus. Inclusion criteria were derived from the review question. Thus, to be included in the review, articles had to report on primary studies conducted on the subject, describe the method of sampling and include measurements of floristic composition on sites that had been subjected to burning. Studies were excluded that had no control or unburnt comparators.

3.4. Study Quality Assessment

Study quality assessment was carried out in order to indicate the level of confidence that may be placed in the results of individual selected articles. Retrieved articles were subject to an evaluation of methodology using a hierarchy of evidence (Appendix 2) adapted from models of the systematic review process used in medicine and public health (Stevens & Milne 1997, Pullin & Knight 2003). Three reviewers assessed each full article independently. Disagreement regarding study quality and inclusion was resolved by reaching consensus. The assessments of study quality are described in the table of included studies (Appendix 3).

3.5. Data Extraction

Relevant primary data were extracted by consensus between two reviewers who shared data handling tasks. Data extracted included: Author, year, reference, the location of the study site(s), the data quality, the length of time since burning was undertaken, the number of species monitored (as a proxy for proportion of habitat studied) and the method associated with recording abundance, the community being burnt, whether the burn was accidental or a management burn, whether burning rotation was studied or post burn recovery, what kind of grazing occurred on the site, the sampling methodology and outcome measures. The table of included studies (Appendix 3) provides a description of the outcome data reported from each dataset and the rationale behind its extraction.

3.6. Data Synthesis

Quantitative changes in the abundance of plant species and area of bare ground resulting from burning were considered as outcome measures and entered into a data matrix. Sites within an experiment were pooled when data quality was high. Site comparisons were not always balanced. Thus where there was more than one burnt site but only one unburnt site the mean of the burnt sites was compared to the unburnt site and *vice versa*. Pooled treatment and control sites were included once to avoid bias with the exception of data on rotational burning. In the latter case both short and long burning rotation treatments utilised the same unburnt control, which was entered twice, thus this data is not independent. Priority was given to the largest time range where there was a choice as they have most long term predictive power. Likewise, grazed sites received priority over ungrazed sites as grazing and burning are carried out concurrently over most of the British uplands.

Qualitative assessment of variation in study characteristics, quality and results was undertaken. The major changes in floristic composition were summarised for each article and interpreted in terms of favourable condition using upland CSM tables. Changes in the abundance of key indicator species were noted and interpreted in terms of changing diversity and dominance. The dominance of a single species was considered negative in terms of favourable condition as was an increase in the amount of bare ground and decrease in species richness.

The use of complementary formal statistical techniques was considered desirable to combine the results of the included studies, to assess heterogeneity, and to quantitatively evaluate possible reasons for variation in the effect of the intervention. Variation in floristic composition between burnt and unburnt sites was analysed using Detrended correspondence analysis (DCA) (Hill 1979, Hill and Gauch 1980) within Windows-based PC-ORD (McCune & Mefford 1999). This allowed an assessment of the degree to which the effects of burning are consistent across different studies. Rare species were down weighted to reduce noise, but not eliminated from the dataset. Relative Euclidean distance was used to determine the percentage of variance in the distance matrix (McCune & Mefford 1999).

Two further DCA's were undertaken firstly eliminating sites with partial data and secondly running an ordination with dummy samples to investigate changes in favourable condition. Four studies were excluded from the second DCA (Hale & Cotton, Rawes-Table 9, Ross-both heavy and light grazing). Two studies were marginal (Elliott, Rawes-Table 15). These were considered as species-poor sites with complete species data and were therefore included. Dummy samples were included in a third DCA in order to facilitate interpretation of changes in floristic composition in terms of favourable condition status. The dummy samples were derived from unburnt samples. Good favourable condition was represented by adding species in the upland CSM table to the data at 10% where they were absent or increasing their abundance by 10% if they were already present. Additionally, any bare ground was eliminated and all species abundances >75% were reduced to 65%. This resulted in increased species richness, promoted co dominance and increased favourable condition status in comparison to the original unburnt data. Poor condition was represented by reducing the abundance of species in the upland CSM table by 10% or where there abundance was <10% eliminating them. 10% was added to bare ground. Where *Molinia caerulea*, *Calluna vulgaris* or *Eriophorum* spp. were present their abundance was increased to 90% (unless they were already present above this threshold). This resulted in decreased species richness, promoted the dominance of a few selected species and decreased favourable condition status in comparison to the original unburnt data. Analysis of Variance was used to examine the significance of differences in DCA axis scores between burnt and unburnt sites. Canonical Correspondence Analysis (CCA) (ter Braak 1986, 1988, 1994 ter Braak & Smilauer 1998) within Windows-based PC-ORD (McCune & Mefford 1999) was used to evaluate possible reasons for variation in the effect of the intervention. Sample scores were derived from Ellenberg's indicator values for British Plants (Hill *et al.* 1999) to assist in interpretation of the CCA ordination. The relationships between Burning (treatment), location, data quality, time since burning, community type, favourable condition, light, moisture, reaction and nitrogen were quantified by CCA. Analysis of Variance was used to examine the significance of differences in Ellenberg's indicator values for British Plants between burnt and unburnt sites.

4. Results

4.1. Review Statistics

A total of 24,484 articles (including duplicates) were identified using the search terms in the computerised databases. A further 15 articles were identified by searching the reference lists of articles. Recognised experts and current practitioners in the field of upland ecology identified 16 articles with one article identified by a contacted author.

Of these articles, 317 were retrieved for full text viewing based upon a screening of title and abstract (where available). Of these, 82 articles were excluded because they presented only secondary information. This information was either unsubstantiated with no data to support the author's comments or referred to primary sources which were retrieved and analysed on their own merits providing they fulfilled the relevance criteria. Of the remaining 235 articles, 77 did not present data on the subject, 58 did not consider burning as a factor or variable, 196 did not have relevant outcomes and 200 did not have a control or unburnt comparator. Thus, a number of articles were excluded on multiple criteria.

Of 158 primary articles that included a relevant subject, a further 36 were excluded as they did not consider burning as a factor or variable, 84 of these did not have relevant outcomes and 15 of these did not have a control or unburnt comparator. Ten articles were unavailable and therefore could not be assessed. A remainder of 13 articles fulfilled the relevance and quality criteria but five of these were duplicates reporting on the results of the same work. The final eight articles reported on the results of 11 datasets and were incorporated in the data extraction and synthesis stages.

4.2 Study quality

Eight articles were included in the analysis with three articles contributing two datasets and the remainder one dataset. Adamson (*pers. comm.*) consists of two non-independent datasets sharing the same control but measuring the effect of burning on both a short and a long rotation. Rawes and Hobbs (1979) consists of two independent site comparisons. Ross, Adamson and Moon (2003) consists of two independent datasets with co-interventions of light and heavy grazing, based on a factorial experiment. See characteristics of included studies tables (Appendix 3) for details of each study.

Design, methods and Data quality.
Of the 11 datasets, five were based on randomized controlled trials whilst six were site comparisons. Sampling methodologies and parameters of abundance varied in rigour from one dataset to the next. Parameters of abundance used for monitoring included frequency measures, occupancy measures and cover assessed by eye. The number of species monitored was also variable. Four datasets reported on selected species, whilst the remainder were assessed as reporting on all species, although two of the datasets had low species richness. Six datasets reported on changes in the abundance of bare ground.

Populations.
The included datasets represented two community types. Seven were assigned to M19 *Calluna vulgaris – Eriophorum vaginatum* blanket mire whilst the remaining four datasets were assigned to M15 *Scirpus cespitosus – Erica tetralix* wet heath. Nine datasets were located in England, ranging from the Peak District along the Pennine chain to Northhumberland. The remaining two datasets were from Ireland.

Interventions.
Of the 11 datasets, two (one article) presented data on rotational burning. Of the nine datasets reporting on post burn recovery one was accidentally burnt, four were management burns and four were experimental burns. Monitoring of treatment effect was undertaken from one to 11 years after burning, with unburnt comparators ranging from 15 to 47 years since burning. All the studies were subject to grazing by sheep in addition to burning with one being grazed by sheep and cattle.

4.3 Outcome of the review

The 11 datasets included in the review show a range of changes in floristic composition in response to burning. Overall, the changes in floristic composition that occurred tended to:

- 1) Promote the dominance of a few species (four datasets) or switch dominance from ericoids to graminoids (two datasets).
- 2) Increase the quantity of bare ground (four datasets) although two datasets resulted in a minimal decrease in bare ground.
- 3) Result in decreased abundance of key species (nine datasets) although two datasets increased the abundance of key species without promoting dominance.
- 4) Result in minor changes in floristic composition (two datasets).

The initial three outcomes result in unfavourable condition (as defined by upland CSM tables) and were therefore considered indicators of degradation whilst the last outcome is neutral in terms of favourable condition indicating that burning does not degrade blanket bog. When changes were detected that might enhance favourable condition status, they were accompanied by negative changes and are therefore contradictory with the exception of Elliott (1953). Three datasets suggest that burning degrades blanket bog, whilst five present contradictory outcomes and three indicate that burning does not degrade blanket bog. Site comparisons generally suggest that burning does not degrade bog (three datasets) or has contradictory effects (two datasets) whilst randomised controlled trials suggest that burning is contradictory (three datasets) or that blanket bog is degraded by burning (two data sets) (Table 1).

Table 1. Outcome (based on ratified CSM) in terms of yes/no/neutral answer to the question 'does burning degrade blanket bog?' Datasets are separated according to quality of methodology.

Quality of evidence	Yes (does degrade)	Contradictory	No (doesn't degrade)
Randomised controlled trials	2	3	0
Site comparisons	1	2	3
Total	3	5	3

Quantitative Synthesis

Quantitative synthesis confirms that there is considerable variation in the response of sites to burning. Five of the datasets increase first axis DCA scores whilst six decrease. There is considerable variation in the magnitude of the change (Fig. 1). Overall, the unburnt sites have a marginally lower mean 1st axis scores than burnt sites (Fig. 2) but this is not significant (ANOVA, F = 0.01, p = 0.929). However, there is a consistent response to burning on the 2^{nd} axis of the DCA (Fig. 1). Unburnt sites all have lower 2^{nd} axis scores than the burnt sites with which they are paired. This suggests that burning tends to increase the abundance of species with high 2^{nd} axis scores relative to the abundance of species with low second axis scores (Table 2). Overall, the unburnt sites have a lower mean 2^{nd} axis scores than burnt sites (Fig. 3) but the difference between burnt and unburnt sites is not significant (ANOVA, F = 1.32, p = 0.264).

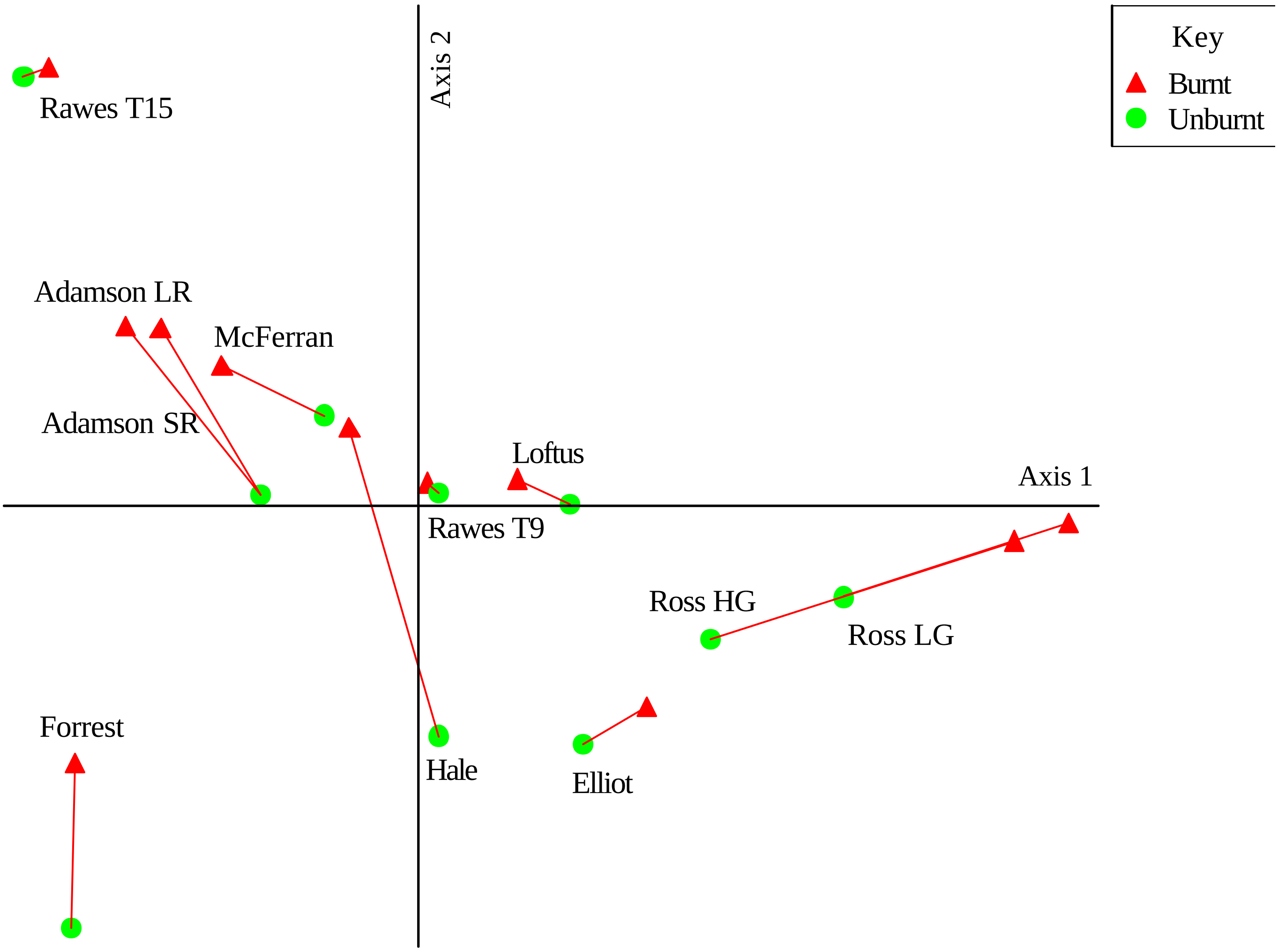

Figure 1. Sample ordination of floristic data from accepted datasets using Detrended Correspondence Analysis. Eigenvalue, axis one = 0.639, axis two = 0.320. Coefficients of determination for the correlations between ordination distances and distances in the original n-dimensional space: axis 1= 0.385, axis 2 = 0.105.

Table 2. High, medium and low Ranked 2nd axis DCA species scores.

High rank 2nd axis scores		Medium rank 2nd axis scores		Low rank 2nd axis scores	
species	**Species score**	**species**	**Species score**	**species**	**Species score**
Calypogeia trichomanis	432	*Nardus stricta*	215	*Lepidozia setacea*	-27
Sphagnum spp.	382	*Eriophorum angustifolium*	213	*Empetrum nigrum*	-33
Lophozia ventricosa	375	*Carex spp*	183	*Sphagnum recurvum*	-42
Bare Ground	335	*Molinia caerulea*	141	*Sphagnum capillifolium*	-47
Sphagnum russowii	303	*Moss sp*	105	*Cephalozia bicuspidata*	-49
Cephaloziella divaricata	303	*Trichophorum caespitosum (Scirpus)*	101	*Mylia spp.*	-65
Mylia taylori	303	*Calluna vulgaris*	91	*Cladonia arbuscula*	-68
Polytrichum spp.	303	*Eurhynchium praelongum*	87	*Aulacomnium palustre*	-71
Algae	289	*Lophocolea bidentata*	87	*Dicranium scoparium*	-71
Campylopus paradoxus	288	*Rhytidiadelpus sqarrosus*	87	*Lophozia spp.*	-77
Calypogeia muelleriana	279	*Erica tetralix*	70	*Odontoschisma sphagni*	-77
Cladonia diversa	273	*Narthecium ossifragum*	48	*Pleurozium schreberi*	-79
Coriscium viride	273	*Vaccinium myrtillus*	38	*Pohlia nutans*	-81
Galium saxatile	248	*Deschampsia flexuosa*	35	*Sphagnum magellanicum*	-91
Juncus bulbosus	248	*Polytrichum commune*	19	*Rhytidiadelpus loreus*	-112
Carex echinata	248	*Hypnum jutlandicum*	12	*Blindia acuta*	-127
Potentilla errecta	248	*Vaccinium vitis-idaea*	9	*Listera cordata*	-127
Erica cinerea	245	*Rubus chamaemorus*	-7	*Vaccinium oxycoccos*	-127
Racomitrium lanuginosum	244	*Sphagnum plumulosum*	-9	*Cladonia fimbriata*	-127
Festuca ovina	243	*Campylopus flexuosus*	-9	*Cladonia squamosa*	-127
Agrostis canina	242	*Cladonia uncialis*	-9	*Polytrichum juniperinum*	-127
Eriophorum vaginatum	229	*Diplophyllum albicans*	-9	*Cephalozia connivens*	-127
Campylopus introflexus	224	*Sphagnum papillosum*	-14	*Parmelia saxatilis*	-127
Juncus sqarrosus	216	*Plagiothecium undulatum*	-20	*Barbilophozia floerkii*	-127
Litter	215	*Cladonia impexa*	-21	*Ptilidium ciliare*	-127

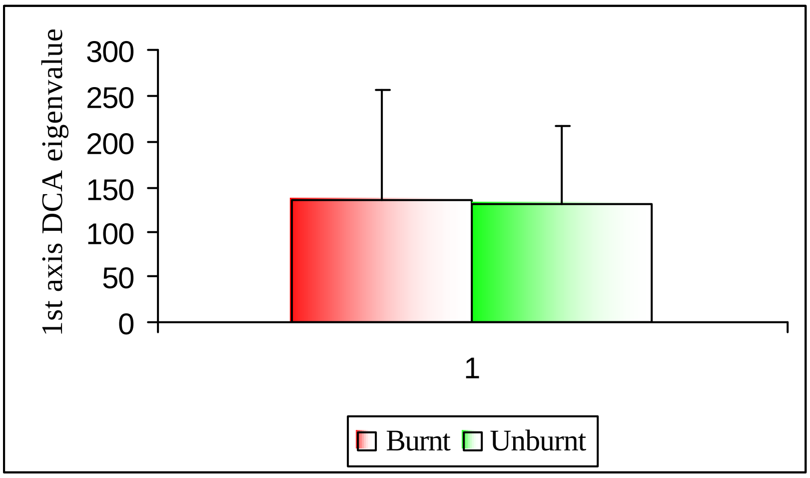

Figure 2. The mean and standard deviation of the1st axis DCA eigenvalues for burnt and unburnt sites from accepted datasets.

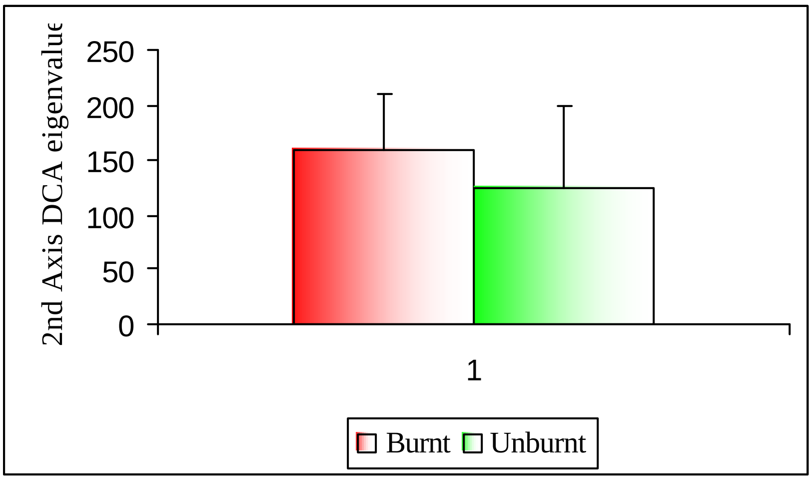

Figure 3. The mean and standard deviation of the2nd axis DCA eigenvalues for burnt and unburnt sites from accepted datasets.

The overall response of sites to burning is more consistent when datasets that do not include all the species on the site are eliminated. Five sites increase both first and second axis scores in response to burning whilst the remaining two sites increase first axis score but decrease the second axis score. Overall, the unburnt sites have lower mean first and second axis scores than burnt sites (Figs 4 and 5) but the difference between burnt and unburnt sites is not significant (axis one, ANOVA, F = 0.1, p = 0.755; axis two ANOVA, F = 0.26, p = 0.62).

Dummy variables were added to the data matrix to facilitate interpretation of changes in floristic composition in terms of favourable condition. Six of the seven sites move from a low to a high first axis score in response to burning, although there is considerable variation in the magnitude of the response. Good condition dummy sites all have lower first axis scores than their poor condition counterparts. Overall, first axis scores increase from sites in good condition, through unburnt sites, to burnt sites, to sites in poor condition (Fig. 6).

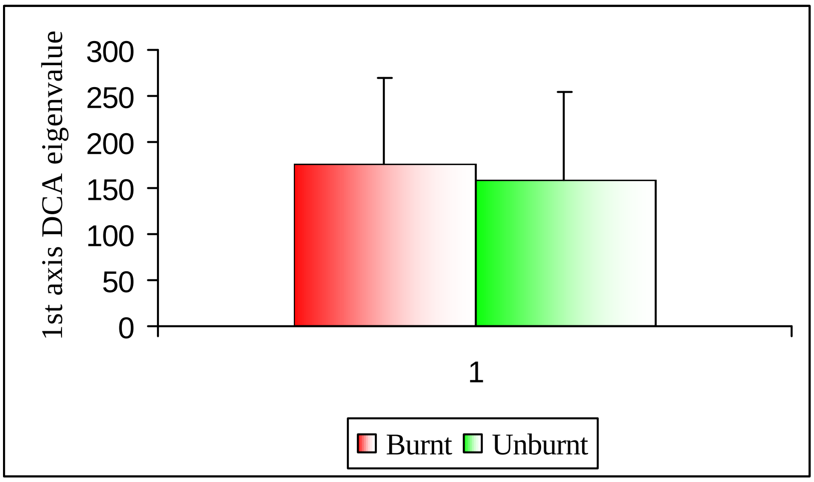

Figure 4. The mean and standard deviation of the1st axis DCA eigenvalues for burnt and unburnt sites from accepted datasets with full suites of species.

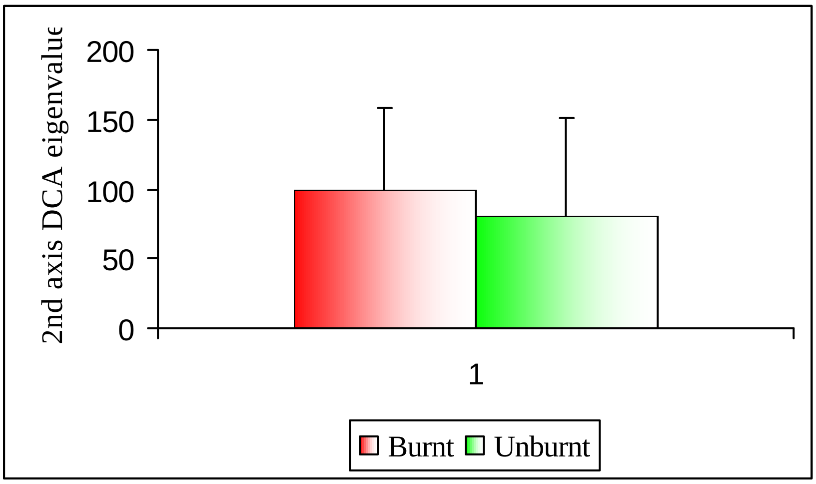

Figure 5. The mean and standard deviation of the 2nd axis DCA eigenvalues for burnt and unburnt sites from accepted datasets with full suites of species.

Canonical Correspondence Analysis was used to relate the changes in floristic composition to a range of explanatory variables (Table 3). The first CCA axis explained 20.9% of the variation, the second axis explained 18.4% whilst the third axis accounted for 17.1% of the variation. All three axes were significant (Monte Carlo test $p < 0.01$).

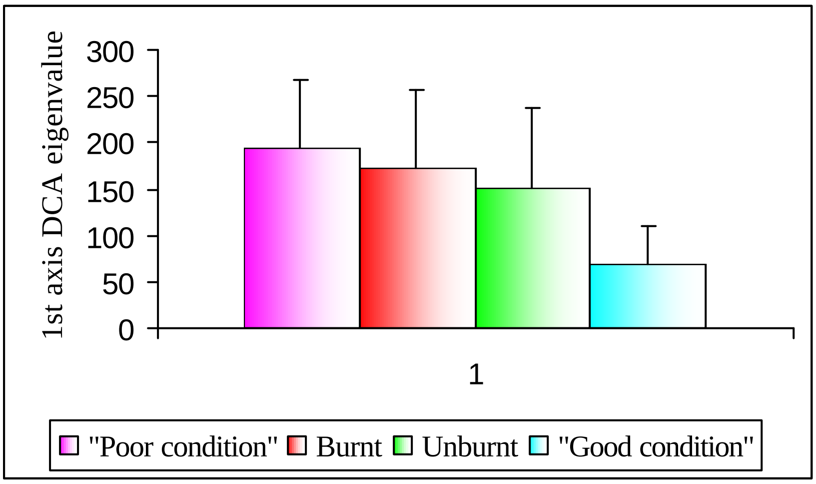

Figure 6. The mean and standard deviation of the1st axis DCA eigenvalues for burnt sites and unburnt sites from accepted datasets with full suites of species and dummy sites in poor and good condition.

The first axis was strongly correlated with 1st axis DCA score (a surrogate for favourable condition) data quality, and soil moisture (Table 3). However, only first axis DCA score had a significant standardized canonical coefficient with the first axis (Table four). The second axis was strongly correlated with community type, nitrogen, pH, location and light (Table 3). DCA score, data quality, light and nitrogen had significant standardized canonical coefficients with the second axis (p <0.01), whilst moisture was less significant (p <0.05). The third axis had significant standardized canonical coefficients with light, moisture, DCA score, nitrogen (p<0.01), time since burning and data quality (p<0.05) (Table 4).

There are significant correlations between Ellenberg's indicator values and also between data quality and both DCA score and time since burning (Table 4). However, there is no significant difference between Ellenberg's indicator values in burnt and unburnt sites (ANOVAs, p >0.05).

Table 3. Inter-set correlations of explanatory variables with the first two axes of CCA.

Explanatory variables	**Inter-set correlations of explanatory variables with axes**	
	Axis one	**Axis two**
Treatment (burnt or unburnt)	-0.084	-0.145
Location (Ireland, C England, N England)	-0.120	0.507
Data quality (randomized control trial or site comparison)	-0.658	0.1
Time since burn (years)	0.29	-0.158
Community type (M15 or M19)	0.098	-0.703
1st axis DCA score	0.949	0.033
Light (Ellenberg indicator value)	0.293	0.502
Moisure (Ellenberg indicator value)	-0.524	0.482
Reaction (Ellenberg indicator value)	-0.059	-0.516
Nitrogen (Ellenberg indicator value)	0.473	-0.531

Table 4. Correlation coefficients between ordination axes and explanatory variables for all accepted articles with a full suite of species. N=14, r>0.661 is significant at p = 0.01 (bold); 0.532< r <0.661 is significant at p = 0.05 (italic); r<0.423 not significant (two-tailed test).

	Axis 1	Axis 2	Axis 3	Treatment	location	Data quality	Time since burn	Community type	DCA score	Light	Moisture	Reaction	Nitrogen
Treatment	0.09	0.02	0.15	1									
Location	0.01	0.11	0.27	0	1								
Data quality	0.26	**1.24**	*0.63*	0	0.51	1							
Time since burning	0.13	0.41	*0.65*	0.39	0.46	*-0.65*	1						
Community type	0.01	0.38	0.16	0	0.13	0.25	0.05	1					
DCA score	*0.63*	**1.79**	**0.88**	0.13	0.32	**0.66**	0.30	0.18	1				
Light	0.35	**0.98**	**1.52**	0.27	0.43	0.22	0.18	*0.53*	0.48	1			
Moisture	0.39	*0.59*	**1.40**	0.12	0.12	0.21	0.47	*0.57*	0.15	**0.72**	1		
Reaction	0.00	0.10	0.14	0.10	**0.73**	0.41	0.18	0.40	0.36	0.46	0.15	1	
Nitrogen	0.13	**0.75**	**0.71**	0.33	*0.62*	0.12	0.21	0.38	0.05	**0.76**	**0.72**	*0.59*	1

Standardized Canonical Coefficients

Raw Correlations among Environmental Variables

5. Discussion

The efficiency of the searching was confirmed by comparison with existing sources of information on burning (Backshall *et al.* 2001, Tucker 2003) and consultation with experts and practitioners. All the references relevant on title and abstract in the English Nature upland management handbook (Backshall *et al.* 2001) and 96% of references in the recent conventional burning review (Tucker 2003) were captured by the search strategy. Twenty four of 52 experts and practitioners responded to our requests for information. In two cases, the unpublished data provided by experts was superior to the information already captured and was therefore included. The value of using experts was proven, both to corroborate the efficiency of the search strategy and to improve the quality of the data included in final synthesis.

On occasion, it was hard to assign articles to communities due to insufficient information in the article or due to the heterogeneous nature of the study site. The inclusion of two of the wet heath articles was marginal. Ultimately, the widespread occurrence of *Eriophorum* spp. and *Trichophorum cespitosum* was used as an indicator of wet conditions. The lack of included articles from Scotland is puzzling given its large extent of blanket bog. However, articles from Scotland were identified in the search strategy but all failed the inclusion criteria. It is possible that searching the Scottish Natural Heritage library would have yielded uncaptured grey literature, some of which may have been of suitable quality for inclusion.

Of the 11 accepted datasets only two (one article) presented data on rotational burning. This highlights a deficiency in the scientific knowledge base on upland management. Further high quality long term research should be commissioned as a priority. Full analysis of the rotational burning data (J. Adamson *pers comm*) is beyond the scope of this work, but should be initiated as soon as possible to inform management decisions.

There is potential variation in the effect of accidental, experimental and management burning but this could not be explored because sample sizes were so small. All the studies were subject to grazing by sheep in addition to burning with one being grazed by sheep and cattle reflecting the ubiquitous use of burning and grazing on British blanket bogs.

The accepted outcomes were changes in floristic composition and the abundance of bare ground. This provided clear guidance on inclusion criteria although interpreting changes in floristic composition in terms of favourable condition and degradation was not straightforward.

A number of references reported on colouration of water as an effect of burning (Martin 1992, Mitchell & McDonald 1995). These did not meet the inclusion criteria as they cannot be interpreted in terms of favourable condition. However, burning has a financial cost to Water utility companies. Paleoecological work was also not included. Causality, scale and defining the timing of the burning intervention were major problems in their interpretation. Some higher quality paleoecological work (Stevenson & Rhodes 2000) suggests that burning can contribute to shifts in dominance from ericoids to graminoids at the watershed scale. This represents a decline in favourable condition. Thus there is some evidence that broadening the outcomes increases the number of negative effects of burning.

There is considerable variation in the changes in floristic composition that occur in response to burning on blanket bog and wet heath. Even where similar communities and interventions are reported on, variation in parameters of abundance and scales (both temporal and spatial) make it difficult to synthesize results across datasets. Nevertheless, it is possible to qualitatively and quantitatively identify some general trends in floristic composition and relate them to favourable condition.

Burning promoted the dominance of *Calluna vulgaris, Eriophorum* spp. or *Molinia caerulea* in four datasets and switched dominance from ericoids to graminoids in two further datasets. This is consistent with current literature on the effects of burning (Shaw *et al.* 1996, Tucker 2003) The dominance of few species results in species poor landscapes generally of low conservation value and therefore is negative in terms of favourable condition.

Burning increased the quantity of bare ground in four datasets. However, it also marginally decreased bare ground in two datasets. There are no obvious reasons for this discrepancy although both datasets in which there is a decline are site comparisons. It seems probable that burning does increase the quantity of bare ground but that other disturbance factors such as grazing are also important. Links between burning and erosion have been shown by a number of studies that did not meet the inclusion criteria because they did not measure bare ground (Tallis 1973, 1987, 1995, Imeson 1971, Kinako & Gimingham 1980, Mackay & Tallis 1996). Increases in the quantity of bare ground are negative in terms of favourable condition because they lead to increased probability of soil erosion.

Burning resulted in the decreased abundance of key species in nine datasets although two datasets increased the abundance of key species without promoting dominance. However, these two datasets only reported on the change in two species. In general, burning decreases the abundance of key species, reduces diversity and can reduce species richness. This is considered negative in terms of favourable condition and is consistent with current literature (Shaw *et al.* 1996, Tucker 2003).

The complex changes in floristic composition in response to burning have contradictory effects in terms of favourable condition in five datasets. Two of these five promote graminoid dominance (negative in terms of favourable condition) but increase Sphagnum abundance (positive in terms of favourable condition). It is often stated that burning is damaging to Sphagnum species (Ratcliffe 1964, Rowell 1990) but there is also some evidence (no control) that Sphagnum can recover within three years of a burn (Hamilton 2001) or even become more abundant after burning (Macdonald *pers comm.*). The remaining contradictory effects result from interactions between changing dominance and changing abundance of key species.

The interpretation of favourable condition is problematic for a number of reasons. Firstly, favourable condition assessment is a field-based technique that involves assessment of vegetation composition and structure at a range of scales. Obviously, only some of this information is presented in articles which tend to focus on changes in floristic composition at a range of within-patch scales. Secondly, different parameters of abundance are used to assess vegetation composition and cover. Favourable condition assessment relies on thresholds based on percentage cover. Thirdly, favourable condition is not measured on a quantitative scale. If an assessment point fails on any feature then it fails overall. Using these criteria when assessing floristic information from articles results in failure before and after burning for many sites, thus contradictory effects are considered negative rather than neutral and burning has no effect despite the changes in floristic composition. It is therefore necessary to treat the interpretation of the changes in floristic composition in terms of favourable condition with caution as they inevitably rely on subjective value judgements and are not robust to changes in favourable condition definition.

The DCA plots corroborate the complexity of changes in floristic composition in response to burning. There is large variation in site response to burning although increasing data quality by eliminating sites without full suites of species does result in more uniformity. DCAs identified a non significant trend in community response to burning. A number of bryophyte species and bare ground appear to be associated with burning. This is consistent with the trends identified in the narrative synthesis. Larger sample sizes would be needed to detect a significant overall response, or to elucidate consistent responses from subgroups of studies with similar initial floristic composition, abiotic environments, treatments and timescales. The DCA ordinations are hard to interpret in terms of favourable condition, but the inclusion of dummy samples suggests that burning degrades blanket bog.

The CCA allowed evaluation of possible reasons for variation in the effect of the intervention and suggested that interactions between data quality, time since burning and abiotic site conditions may play an important role in determining the outcome of burning.

First axis DCA score was used as a surrogate for favourable condition because there was a significant difference between first axis DCA score for dummy samples. First axis DCA score was significantly correlated with three CCA axes. This is expected as the first DCA axis represents a major pattern of variation in the data. There is a significant correlation between DCA first axis score and data quality. This is consistent with the findings that high quality data (randomized controlled trials) suggest that burning degrades bog, whilst intermediate quality data (site comparisons) suggest that burning is neutral in effect. Such discrepancies in results between variable quality investigations are commonly found in systematic reviews (Egger *et al.* 2001).

Time since burning also varied from one study to the next and had a bearing on the outcome. Monitoring of treatment effect was undertaken from one to 11 years after burning, with unburnt comparators ranging from 15 to 47 years since burning. Time since burning was significantly correlated with the third CCA axis suggesting that this is an important variable in explaining community response to burning. Post burn times of 0-7 years resulted in four contradictory outcomes whilst three datasets suggested burning resulted in degradation and one results in no change. Post burn times of >7years resulted in one contradictory result whilst two datasets suggest that burning does not degrade blanket bog.. It is therefore unclear if the negative effects of burning persist with time. Small sample sizes make further interpretation difficult. It is interesting to note that whether a site was burnt or not was not significant although the time since burning was.

Ellenberg light, nitrogen and moisture values were significantly correlated with the second and third CCA axes. However, there were no significant differences in Ellenberg values between burnt and unburnt sites. Unsurprisingly, there are intercorrelations between Ellenberg indicator values and correlations between community type and Ellenberg indicator values. Small sample sizes and the lack of significance prevent any inferences being drawn regarding the potential modifying effects of variables such as community type, grazing and soil moisture.

The interpretation of the correlations derived from the CCA should be treated with considerable caution due to the small sample sizes. Large numbers of explanatory variables relative to number of samples yield increasingly spurious correlations (McCune & Mefford 1999). However, CCA and DCA remain useful tools for examining multivariate data. If samples sizes had been sufficient and variance data was extracted, the magnitude and direction of vectors could potentially have been analysed using meta-analytical techniques to provide information on the possible influence of effect modifiers.

6. Reviewers' Conclusions

6.1 Implications for conservation practice

There are no consistent significant changes in floristic composition in response to burning but a trend towards increases in the abundance of bryophytes and bare ground has been identified. Burning also tended to promote the dominance of a few species or switch dominance from ericoids to graminoids and decreased the abundance of key species as defined in the upland CSM tables. These changes were interpreted as negative in the context of favourable condition criteria suggesting that burning degrades blanket bog. However, there were also minor changes in floristic composition and contradictory changes e.g. dominance decreased but the abundance of key species also declined. One study, showed a reduction in graminoid dominance that was not coupled with negative changes, thus in one instance, burning had a positive outcome. Overall, the weight of available evidence suggests that burning either degrades blanket bog or is contradictory in effect. If quality of evidence is used to discriminate among studies then the evidence for degradation becomes stronger. However, a degree of circumspection is required given the small sample size, variable timescales of the studies and problems in the interpretation of favourable condition. Pending further research it is suggested that burning on blanket bog and wet heath should normally be avoided if favourable condition is to be achieved or maintained, but there is not a robust evidence-base to support management decisions regarding burning on blanket bog.

6.2 Implications for research

There is only one study that examines the effect of rotational burning on changes in floristic composition on blanket bog and wet heath in Britain. This highlights a deficiency in the scientific knowledge base on upland management. Full analysis of the rotational burning data (J. Adamson *pers comm* 2004) is beyond the scope of this work, but should be initiated as soon as possible to inform management decisions. Further high quality long term research should be commissioned as a priority. Whilst long term factorial experiments would be desirable they are also expensive. Investigations combining paleoecological techniques with contemporary vegetation analysis e.g. Stevenson *et al.* (1996) provide an alternative methodology for obtaining data on the effects of serial burning.

The interpretation of favourable condition also poses problems for future research. Favourable condition assessment requires information about vegetation structure as well as composition. Very few studies are explicit about vegetation structure, other than records of stand age and vegetation height. This should be rectified in future work. However, problems of interpretation remain as condition assessment is a field based exercise. Monitoring of favourable condition is required to ascertain the effect of management in terms of favourable condition criteria. This should be undertaken using fixed sampling points. Potential sources of heterogeneity in the results should be defined *a priori* and sampling methodology should be stratified to account for these potential effect modifiers. Power analysis should also be undertaken when pilot data become available to ensure that samples sizes are sufficient to detect significant effects (Brown 2001).

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8. References

Backshall, J., Manley, J. *et al*. Eds. (2001). *The upland management handbook*. Peterborough, English Nature.

Brown, A. (2001) Habitat monitoring for conservation management and reporting 3: Technical Guide. *Integrating monitoring with management planning: A demonstration of good practice on Natura 2000 sites in Wales*. Life-Nature Project no LIFE95 NAT/UK/000821. Countryside Council for Wales.

Egger, M., Smith, G.D. & Altman, D.G. (Eds.) (2001). *Systematic Reviews in Health Care. Meta-analysis in context*. British Medical Journal Publishing Group, London.

Elliott, R. J. (1953). The *effects of burning on heather moors of the south Pennines*. University of Sheffield PhD, Sheffield.

Forrest, G. I. & Smith, R. A. H. (1975). "The Productivity of a Range of Blanket Bog Vegetation Types in the Northern Pennines." *The Journal of Ecology* **63**(1), 173-202.

Hale, W. H. G. & Cotton, D. E. (1988). "The management of vegetation change in Ilkley Moor." *Aspects of Applied Biology* **16**, 311-316.

Hamilton, A. (2000) *The characteristics and effects of management fire on blanket-bog vegetation in north-west Scotland*. PhD thesis, University of Edinburgh, Edinburgh.

Hill, M.O., Mountford, J.O., Roy, D.B. & Bunce, R.G.H. (1999) *Ellenberg's indicator values for British plants.* ECOFACT Volume 2 Technical Annex, HMSO, Norwich.

Hill, M. O. & Gauch, H.G. (1980) Detrended correspondence analysis: an improved ordination technique. *Vegetatio* **42**, 47-58.

Hill, M.O. (1979) *DECORANA: a FORTRAN program for detrended correspondence analysis and reciprocal averaging.* Ithaca, NY. Ecology and Systematics, Cornell University.

Imeson, A.C. (1971) Heather burning and soil erosion on the North Yorkshire Moors. *Journal of Applied Ecology* **8**, 537-542.

JNCC (2004) Common Standards Monitoring Guidance For Upland Habitats.

Khan, K.S., Ter Riet, G., Glanville, J., Sowden, A.J. & Kleijnen, J. (2001) *Undertaking Systematic reviews of Research on Effectiveness. CRD's Guidance for those Carrying*

Out or Commissioning Reviews. CRD Report Number **4.** (2nd Edition), NHS Centre for Reviews and Dissemination, University of York.

Kinako, P. D. S. & Gimingham, C.H. (1980). Heather burning and soil erosion on upland heaths in Scotland. *Journal of. Environmental. Management.* **10**, 277-284.

Mackay, A. W. & Tallis, J.W. (1996). Summit-type blanket mire erosion in the forest of Bowland, Lancashire, UK: Predisposing factors and implications for conservation. *Biological Conservation* **76**(1), 31-44.

Martin, D. S. J. (1992). *The influence of land management on upland water quality notably the production of soluble colour in supply*. University of Leeds PhD, Leeds.

McCune, B. & Mefford, M.J. (1999) *PC-ORD. Multivariate analysis of ecological data, version 4*. MjM Software design, Gleneden Beach, Oregon, USA.

Mitchell, G. & McDonald, A.T. (1995). Catchment Characterization as a Tool for Upland Water-Quality Management. *Journal of Environmental Management* **44**(1), 83-95.

Pullin, A.S. & Knight, T.M. 2001. Effectiveness in conservation practice: pointers from medicine and public health. *Conservation Biology* **15**, 50-54.

Pullin, A.S. & Knight, T.M. 2003. Support for decision making in conservation practice: an evidence-based approach. *Journal for Nature Conservation* **11**, 83-90.

Ratcliffe, D.A. (1964) Mires and Bogs, In: J. H. Burnett (Ed.) *The vegetation of Scotland*, p426-478. Oliver & Boyd, Edinburgh.

Rawes, M. & Hobbs, R. (1979). "Management of Semi-Natural Blanket Bog in the Northern Pennines." *The Journal of Ecology* **67**(3), 789-807.

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

Ross, S. Adamson, H. & Moon, A. (2003). Evaluating management techniques for controlling Molinia caerulea and enhancing Calluna vulgaris on upland wet heathland in Northern England. *Agriculture, Ecosystems and Environment* **97**, 39-49.

Rowell, T.A. (1990) Management of peatlands for conservation. *British Wildlife* **1**, 144-156.

Shaw, S.C., Wheeler, B.D., Kirby, P., Phillipson, P. & Edmunds, R. (1996) Literature review of the historical effects of burning and grazing of blanket bog and upland wet heath. *English Nature Research Report* No **172**.

Stevens, A. and Milne, R. (1997). The effectiveness revolution and public health. In: G. Scally (Ed.) *Progress in Public Health*, p197-225. Royal Society of Medicine Press, London.

Stevenson, A. C. & Rhodes, A.N. (2000). Palaeoenvironmental evaluation of the importance of fire as a cause for Calluna loss in the British Isles. *Palaeogeography Palaeoclimatology Palaeoecology* **164**(1-4), 195-206.

Stevenson, A. C., Rhodes, A.N., Kirkpatrick, A.H. & MacDonald, A.J. (1996) *The determination of fire histories and an assessment of their effects on moorland soils and vegetation*. Scottish Natural Heritage Research, Survey and Monitoring Report no.16, SNH, Edinburgh.

Tallis, J. H. (1995). Climate and erosion signals in British blanket peats: The significance of Racomitrium lanuginosum remains. *Journal of Ecology* **83**(6), 1021-1030.

Tallis, J. H. (1987). Fire and flood at Holme Moss: erosion processes in an upland blanket mire. *Journal of Ecology* **75**(4), 1099-1129.

Tallis, J. H. (1973). Studies on Southern Pennine Peats: V. Direct Observations on Peat Erosion and Peat Hydrology at Featherbed Moss, Derbyshire. *The Journal of Ecology* **61**(1), 1-22.

Ter Braak, C. J. F. (1986) Canonical correspondence analysis: a new eigenvector technique for multivariate direct gradient analysis. *Ecology* **67**, 1167-1179.

Ter Braak, C.F.J. (1988) CANOCO - an extension of DECORANA to analyse species-environment relationships. *Vegetatio* **75**, 139-160.

Ter Braak, C.J.F. (1994) Canonical community ordination. Part I: Basic theory and linear methods. *Ecoscience* **1**, 127-140.

Ter Braak, C.J.F. & Smilauer, P. (1998) *CANOCO reference manual and users guide to CANOCO for windows: Software for community ordination (Version 4).* Wageningen, Centre for Biometry.

Tucker, G. (2003) *Review of the impacts of heather and grassland burning in the uplands on soils, hydrology and biodiversity* - Report to English Nature.

Appendix 1. Full list of terms used in electronic searches

We searched each information source using a Boolean-type strategy employing both specific and general terms (e.g. burn* AND Calluna; * denotes a wildcard for use with truncated terms). Search terms were not combined using the Boolean operator 'OR', because we found that in the Web of Science database, such strategies produced consistently fewer hits than the sum of separate searches using only the 'AND' operator. These strategies were used for every source to ensure strict comparability of results. The full list of search terms are shown below.

1. burn* AND calluna
2. burn* AND dwarf AND shrub*
3. burn* AND empetrum
4. burn* AND erica
5. burn* AND heath*
6. burn* AND upland*
7. burn* AND vaccinium
8. fire* AND calluna
9. fire* AND dwarf AND shrub*
10. fire* AND heath*
11. fire* AND upland*
12. moor* AND burn*
13. moor* AND fire*
14. muirburn*
15. burn* AND bog*
16. burn* AND mire*
17. burn* AND peat
18. burn* AND Eriophorum
19. burn* AND Scirpus
20. burn* AND Trichophorum
21. burn* AND Molinia
22. burn* AND Sphagnum
23. fire* AND bog*
24. fire* AND mire*
25. fire* AND peat
26. fire* AND Eriophorum
27. fire* AND Scirpus
28. fire* AND Trichophorum
29. fire* AND Molinia
30. fire* AND Sphagnum.

Appendix 2. Hierarchy of evidence based on the type of research undertaken. Note: This hierarchy may be specific to this review.

Cat.	Quality of evidence - Conservation
I:	Strong evidence obtained from at least one properly designed; randomized controlled trial.
II-1:	Evidence from well designed controlled trials without randomization.
II-2:	Evidence from a comparison of differences between sites with and without a recent burning intervention
II-3:	Evidence obtained from a time series with a baseline established before the burning intervention.
III	Opinions of respected authorities based on qualitative field evidence, descriptive studies or reports of expert committees with appropriate comparator.
IV	Evidence inadequate owing to problems of methodology e.g. sample size, length or comprehensiveness of monitoring or, conflicts of evidence.

Appendix 3. Characteristics of included studies

Study	Adamson *Pers comm* (2004) Environmental Change Network Hard hill burning Moorhouse data. SR (short rotation)
Location and community	Moorhouse NNR, N Pennines: M19 *Calluna-Eriophorum* blanket bog
No of species monitored and method	All species monitored using pin frames
Sampling methodology and experimental protocol	4 replicate blocks allow comparison of burning on 10 year rotation with unburnt controls
Study methodology	Randomized controlled trial
Burning method and grazing	4 burning rotations on a 10 year cycle since 1954, sheep grazing
Post burn time	7 years since last burn from monitoring in 2001. Unburnt comparator not burnt for 47 years
Outcome: Floristic composition	Dominance switches from *Calluna* to *Eriophorum* Bare ground increases minimally *Rubus chamaemorus,,Empetrum nigrum* and *Vaccinium vitis idaea* decrease slightly with a large *Calluna* decline and increase in *Eriophorum* spp. There are other minor changes in floristic composition
Favourable condition interpretation	Graminoids increase (negative) whilst combined ericoid occupancy falls from 98% to 10% (positive as it passes the 75% threshold). Overall, therefore this becomes **Contradictory**
Notes	This would be considered negative if ericoid occupancy was considered on a species by species basis, as burning promotes graminoid dominance and declines in key species abundance.

Study	Adamson *Pers comm* (2004) Environmental Change Network Hard hill burning Moorhouse data. LR (long rotation)
Location and community	Moorhouse NNR, N Pennines: M19 *Calluna-Eriophorum* blanket bog
No of species monitored and method	All species monitored using pin frames
Sampling methodology and experimental protocol	4 replicate blocks allow comparison of burning on 20 year rotation with unburnt controls (The unburnt controls are identical to those used in the short rotation experiment)
Study methodology	Randomized controlled trial
Burning method and grazing	2 burning rotations on a 20 year cycle since 1954, sheep grazing
Post burn time	7 years since last burn from monitoring in 2001. Unburnt comparator not burnt for 47 years
Outcome: Floristic composition	Dominance switches from *Calluna* to *Eriophorum angustifolium* Bare ground increases minimally *Calluna vulgaris* declines with small decreases in *Empetrum nigrum, Vaccinium vitis idaea, Vaccinium myrtillus* and *Rubus chamaemorus*. *Eriophorum* spp increase particulary *E. angustifolium*. There are other minor changes in floristic composition
Favourable condition interpretation	Burning promotes graminoid dominance and declines in key species abundance. **Negative**

Study	Elliott, R. J. (1953). "The effects of burning on heather moors of the south Pennines." Sheffield: University of Sheffield, 1953 PhD.
Location and community	Ringinglow Bog, Peak District: M15 *Scirpus-Erica* wet heath
No of species monitored and method	10 species monitored (It is assumed that this is all species on a species poor site) using frequency.
Sampling methodology and experimental protocol	Frequency values based on 50 quadrats in stands 9-11 years old, and adjacent stands 20 years old.
Study methodology	Site comparison
Burning method and grazing	Accidental burn, sheep grazing
Post burn time	10 years since last burn from monitoring. Unburnt comparator not burnt for 20 years (Dates from eye witnesses, game keepers and *Calluna* ring counts
Outcome: Floristic composition	Bare ground decreases minimally *Empetrum nigrum, Vaccinium myrtillus*, and *Vaccinium vitis idaea* decline in abundance whilst *Calluna* increases. There is a large decrease in abundance of *Deschampsia flexuosa*
Favourable condition interpretation	Although ericoid diversity falls, combined ericoid occupancy increases from 62% to 65% due to the large increase in *Calluna*. The decrease in abundance of *Deschampsia flexuosa* is not covered by blanket bog CSM but can be considered positive (reduction in graminoid dominance). Overall, therefore this becomes **Positive**
Notes	This would be considered negative if ericoid occupancy was considered on a species by species basis, as burning promotes declines in key species abundance and ericoid diversity.

Study	Forrest, G. I. and R. A. H. Smith (1975). "The Productivity of a Range of Blanket Bog Vegetation Types in the Northern Pennines." The Journal of Ecology 63(1): 173-202.
Location and community	Moorhouse NNR, N Pennines: M19 *Calluna-Eriophorum* blanket bog
No of species monitored and method	All species monitored using frequency
Sampling methodology and experimental protocol	Frequency values based on 50 quadrats. Burnt grazed site compared to five unburnt grazed sites.
Study methodology	Site comparison
Burning method and grazing	Unknown. Assumed to be conventional management burning, sheep grazing (0.13 sheep/ha)
Post burn time	9 years since last burn from monitoring. Unburnt comparator not burnt for 30 years.
Outcome: Floristic composition	*Eriophorum angustifolium* becomes dominant *Empetrum nigrum, Rubus chamaemorus* and *Vaccinium oxycoccus*, all decline whilst *Eriophorum angustifolium* and *Trichophorum cespitosum* rise. Many bryophytes and lichens decline in abundance but *Sphagnum papillosum* and *S. recurvum* increase
Favourable condition interpretation	Burning promotes graminoid dominance (negative), reduces ericoid diversity (negative) but increases *Sphagnum* abundance (positive). Overall, **Contradictory**

Study	Hale, W. H. G. and D. E. Cotton (1988). "The management of vegetation change in Ilkley Moor." Aspects of Applied Biology No.16: 311-316.
Location and community	Ilkley Moor, Pennines: M15 *Scirpus-Erica* wet heath
No of species monitored and method	7 species and bare ground monitored using percentage cover by eye
Sampling methodology and experimental protocol	5 replicate blocks allow comparison of burnt and unburnt treatments based on 20 quadrats in treatment plots and 11 quadrats in control plots.
Study methodology	Randomized controlled trail
Burning method and grazing	Experimental burning undertaken to emulate normal management burns, sheep grazing
Post burn time	5 years since last burn from monitoring. Not known when Unburnt comparator was last burnt. Assumed to be 15 years.
Outcome: Floristic composition	Large increase in bare ground *Empetrum nigrum* and *Vaccinium myrtillus* decline. There are other minor changes in floristic composition
Favourable condition interpretation	Both ericoid diversity and combined occupancy decline (83% to 56%). The decline in occupancy is positive as it passes the 75% threshold. The increase in bare ground is negative. Overall **Contradictory**
Notes	This would be considered negative if ericoid occupancy was considered on a species by species basis, as burning reduces ericoid diversity and promotes declines in key species abundance.

Study	Loftus, M. C. P. (1994). "The ecology and management of upland vegetation in the Wicklow Mountains (BL)." D.Phil., New University of Ulster, 48-1328.
Location and community	Wicklow Mountains, Ireland: M19 *Calluna-Eriophorum* blanket bog
No of species monitored and method	All species monitored using pin frames
Sampling methodology and experimental protocol	3 grazed and recently burnt sites are compared to 3 grazed unburnt sites using 2400 pin hits (inclined pin frames) at each site
Study methodology	Site comparison
Burning method and grazing	Management burn, sheep grazing
Post burn time	Three treatment sites burnt<3 years from monitoring. Not known when Unburnt comparator was last burnt. Assumed to be >20 years.
Outcome: Floristic composition	There are minor changes in floristic composition including minor changes in key CSM table species.
Favourable condition interpretation	Burning results in low magnitude changes in floristic composition. **No change (Positive)**

Study	McFerran, D. M. (1991). "The impact of burning and grazing on upland vegetation and invertebrate communities in Co. Antrim." Ph.D., Queen's University Belfast, 41-7663.
Location and community	Glenwherry, N Ireland: M19 *Calluna-Eriophorum* blanket bog
No of species monitored and method	All species monitored using point quadrats, permanent quadrats and pins.
Sampling methodology and experimental protocol	Replicated experiment but discrepancies between method and results mean data is considered as a site comparison.
Study methodology	Site comparison
Burning method and grazing	Experimental burning undertaken to emulate normal management burns, sheep and cattle grazing
Post burn time	1 year since last burn from monitoring. Unburnt comparator not burnt for >20 years.
Outcome: Floristic composition	Bare ground decreases minimally *Calluna vulgaris, Eriophorum vaginatum* and bryophytes decline
Favourable condition interpretation	Burning promotes a decline in the abundance of key species. **Negative**

Study	Rawes, M. and R. Hobbs (1979). "Management of Semi-Natural Blanket Bog in the Northern Pennines." The Journal of Ecology 67(3): 789-807. T9 (based on data in table 9)
Location and community	Moorhouse NNR, N Pennines: M19 *Calluna-Eriophorum* blanket bog
No of species monitored and method	2 species monitored on Domin scale using 25 quadrats
Sampling methodology and experimental protocol	Site comparison based on 25 quadrats at each site.
Study methodology	Site comparison
Burning method and grazing	Management burn, sheep grazing
Post burn time	11 years since last burn from monitoring. Unburnt comparator is steady state. Assumed to be unburnt for >20 years.
Outcome: Floristic composition	*Calluna vulgaris* and *Eriophorum vaginatum* rise slightly in abundance
Favourable condition interpretation	Only have data on two species which show minor changes in abundance. **No change (Positive)**

Study	Rawes, M. and R. Hobbs (1979). "Management of Semi-Natural Blanket Bog in the Northern Pennines." The Journal of Ecology 67(3): 789-807. T15 (based on data in table 15)
Location and community	Moorhouse NNR, N Pennines: M19 *Calluna-Eriophorum* blanket bog
No of species monitored and method	All species monitored using point quadrats
Sampling methodology and experimental protocol	Site comparison based on mean value per ten pin frame
Study methodology	Site comparison
Burning method and grazing	Management burn, sheep grazing
Post burn time	7 years since last burn from monitoring. Not known when Unburnt comparator was last burnt. Assumed to be >15 years.
Outcome: Floristic composition	*Eriophorum vaginatum* becomes dominant Large increase in bare ground *Eriophorum angustifolium* is lost whilst *Eriophorum vaginatum* increases. Many bryophytes decline in abundance but *Sphagnum* spp. increase
Favourable condition interpretation	Burning promotes graminoid dominance (negative) but increases *Sphagnum* abundance (positive). Overall, **Contradictory**

Study	Ross, S. Adamson, H. Moon, A. (2003). " Evaluating management techniques for controlling Molinia caerulea and enhancing Calluna vulgaris on upland wet heathland in Northern England." Agriculture, Ecosystems and Environment 97: 39-49. LG (light grazing)
Location and community	Redesdale, Northhumberland: M15 *Scirpus-Erica* wet heath
No of species monitored and method	2 species monitored using occupancy in 100 cells
Sampling methodology and experimental protocol	3 replicate blocks with 5 permanent quadrats per block in burnt and unburnt treatments.
Study methodology	Randomized controlled trial
Burning method and grazing	Experimental burning undertaken to emulate normal management burns, sheep grazing (0.66 ewes/ha).
Post burn time	3 years since last burn from monitoring. Unburnt comparator not burnt for >20 years.
Outcome: Floristic composition	*Calluna vulgaris* declines in abundance whilst *Molinia caerulea* increases
Favourable condition interpretation	Burning results in a reduction in *Calluna vulgaris* abundance and increases *Molinia caerulea* abundance (negative) but *Calluna vulgaris* was dominant and burning is promoting co dominance (positive). Overall, **Contradictory**

Study	Ross, S. Adamson, H. Moon, A. (2003). " Evaluating management techniques for controlling Molinia caerulea and enhancing Calluna vulgaris on upland wet heathland in Northern England." Agriculture, Ecosystems and Environment 97: 39-49. HG (heavy grazing)
Location and community	Redesdale, Northhumberland: M15 *Scirpus-Erica* wet heath
No of species monitored and method	2 species monitored using occupancy in 100 cells
Sampling methodology and experimental protocol	3 replicate blocks with 5 permanent quadrats per block in burnt and unburnt treatments.
Study methodology	Randomized controlled trial
Burning method and grazing	Experimental burning undertaken to emulate normal management burns, sheep grazing (1.55 ewes/ha).
Post burn time	3 years since last burn from monitoring. Unburnt comparator not burnt for >20 years.
Outcome: Floristic composition	*Molinia caerulea* becomes dominant *Calluna vulgaris* declines in abundance whilst *Molinia caerulea* increases
Favourable condition interpretation	Burning promotes *Molinia caerulea* dominance. **Negative**