Evidence Table

Name of Evidence Review:	Natural England Uplands Evidence Review
Name of Review Topic:	What are the effects of managed burning on the maintenance and restoration of upland peatland biodiversity and the provision of ecosystem services?
Review Question(s)	What are the effects of managed burning on the maintenance and restoration of the characteristic floristic composition, structure and function of upland peatland habitats?

Study details	Authors	Hamilton, A
	Year	2000
	Aim of study	*Key ones relevant to the review:* describe and quantify the fuels available on blanket-bog ; quantify the type and amount of fuel consumed in fires ; determine t he effect of fire on the *Sphagnum* layer, in particular with respect t o position, fuel, and fire characteristics; determine the rate of recovery of *Sphagnum* after fire, and the effect of grazing; determine whether fire does result in more *Calluna* and *Molinia* being available to herbivores, and whether burnt areas are grazed more than unburnt areas.
	Study design	Correlation and Experimental
	Quality score	2-
	External validity	EV-
Population and setting	Source population	Blanket bog of NVC 17 (plus M15 and M18)

	Eligible population	Typical blanket bog – mainly M17.
	Inclusion and exclusion criteria	Sites selected as typical blanket bog – "most commonly M17". Sites selected within areas identified by managers as to be included in their burning programme and to be close to roads for ease of access with equipment.
	Setting	Blanket bog in Coigach and Assynt, N W Scotland
Methods of allocation to intervention/control	Methods of allocation	Plot selection stratified to focus on Shrub/Sphagnum interface (non-random). Within plots sample sites located at random along transects laid out to avoid obvious habitat changes.
	Intervention description	Management burns
	Control/comparison description	All sites burned.
	Sample sizes	Correlation study 4 sites x 4 plots (1996), 3 sites x 10 plots (1997). Experimental study 5 sites with 56 sample plots.
	Baseline comparisons	n/a
	Study sufficiently powered	
Outcomes and methods of analysis (inc effect size, CIs for each outcome and significance)	Primary outcome measures	Measures of fuel load and fire intensity *Sphagnum* condition scores
	Secondary outcome measures	

	Follow-up periods	n/a
	Methods of analysis	
Results		Results indicate that a sizable proportion of the *Sphagnum* recovers in the first two years after a fire. Removal of litter by fire may create conditions for effective re-growth of Sphagnum. Damage to *Sphagnum* is affected by fire intensity and there is some evidence that damage is worse where there is more (tall) *Calluna*. This may be due to differences in the character of the fire or to fuel load but experiments including additional of fuel did not produce that effect.
Notes	Limitations identified by author	Results are observations based on single events – the study does not provide information about the long term effects of fire.
	Limitations identified by review team	Grazing effects are uncertain – no attempts to standardise / control for grazing so actual rates of grazing are unknown. Experiments to test the hypothesis that effect on Sphagnum is increased where there are high fuel loads were ineffective and so inconclusive.
	Evidence gaps and/or recommendations for further research	Long term effects of fire uncertain – comparison of burned and unburned sites.
	Sources of funding	PhD Studentship – Wolfson Trust, University of Edinburgh, SNH and Carnegie Trust.

Hamilton investigated fuel load and fire characteristics in blanket bog vegetation in the North West Highlands of Scotland. The recovery of Sphagnum was investigated in relation to fuel load and fire intensity. The vegetation studied was predominantly NVC M17 bog but with some M15 and M18. Study sites were mainly dictated by the location of management burns carried out by the land managers but were chosen so as to be typical and for proximity to roads for ease of access. Within sample locations sample plots were located randomly along 40m or 2x20m transects. Sample plots were paired to allow grazed and ungrazed treatments (the latter protected by cages).

In 1996 four sites were used to record vascular plant regrowth and recovery of the *Sphagnum* layer after fire. These sites were first visited between 2 and 6 days after they were burnt. In 1997 three sites were set up primarily to record maximum fire temperatures, fuel load, and effects of increased fuel load, but loss of samples and data meant that the only data available recorded the recovery of the Sphagnum layer. In 1998 experimental burns were used to record the temperature regime of fires and quantify fire intensity. Five sites were used, with some plots being harvested (to develop fuel loading equations) and others being burnt. *Sphagnum* recovery was also recorded on these sites.

This work has demonstrated that simple and accurate equations to predict different fuel types can be developed for fuels in the blanket-bog habitat. The results from these equations to predict prefire loading emphasise the variability in fuels across the habitat, and thus the need for more than `spot' sampling of fuels, as has been the general practice in UK fire studies. The fire characteristics results (temperature, intensity) are broadly comparable to those obtained from previous studies in heathland habitats in the UK and results confirm that variability is a key feature of all fires, but in particular those in blanket bog. The main reason for fire variability is the spatial patchiness of the fuel complex, and to a lesser degree the extreme moisture gradients encountered in the fuels e.g. in relation to the topography of the bog surface. Experimental burns included addition of fuel too half of the individual flat plots dried birch twigs, up to a maximum of 0.5 cm in diameter.

The results from all sites show the large variation in the effects of fire on *Sphagnum* condition between sites. The results show that the amount of *Calluna* (as measured by the score value and height) has a significant effect on the condition score of the *Sphagnum*. This may be due to differences in the character of fuel where there is tall *Calluna*, topography (*Calluna* on bogs is often associated with a hummock, resulting in drier fuel) or other factors. It is unlikely that fuel load alone is responsible for the differences in condition scores because no significant changes in Sphagnum conditions score resulted from adding extra fuel. A significant relationships between the condition scores and fire temperature characteristics suggest that these are important factors in determining the damage caused to the *Sphagnum* layer by fire. Grazing appears to reduce effectiveness of *Sphagnum* recovery perhaps through trampling. Observations suggested that fire may aid Sphagnum regrowth in some situations – perhaps through removing litter which otherwise swamps / shades the moss surface.

Evidence Table

Name of Evidence Review:	Natural England Uplands Evidence Review
Name of Review Topic:	What are the effects of managed burning on the maintenance and restoration of upland peatland biodiversity and the provision of ecosystem services?
Review Question(s)	e) severity of burns and c) carbon.

Study details	Authors	HARRIS *et al*.
	Year	2011a
	Aim of study	To consider the fire characteristics and vegetation biomass reduction in a sample of managed burns on one Peak District blanket bog moorland.
	Study design	2: correlation study. [Could also be considered as a case-study (3).]
	Quality score	2+
	External validity	EV-
Population and setting	Source population	Fire temperature was measured at the vegetation base and canopy at four sample points in each burn and biomass reduction was measured through a comparison of pre-and post burn data.
	Eligible population	New (routine) management burns on one Peak District blanket bog site.
	Inclusion and exclusion criteria	NA

	Setting	Howden Moor in the Peak District (Dark/North Peak).
Methods of allocation to intervention/control	Methods of allocation	NA
	Intervention description	Managed burning.
	Control/comparison description	NA
	Sample sizes	17 (‘pressurised fuel assisted’) ‘cool’ management burns (in March and April) on Howden Moor in the Peak District. Four sample measurements made in a zig-zag pattern within each area to be burned.
	Baseline comparisons	Pre-burn vegetation.
	Study sufficiently powered	NR
Outcomes and methods of analysis (inc effect size, CIs for each outcome and significance)	Primary outcome measures	Dried weight of cut fractions (*Calluna*, litter, graminoids, moss and animal excrement) before and after burning and hence biomass loss.
	Secondary outcome measures	Cover by individual species in 50 cm x 50 cm quadrat, then harvested. In an associated quadrat (in a random direction from the vegetation quadrat) temperature was measured at two heights using thermocouples.
	Follow-up periods	Immediate post-burn effect.
	Methods of analysis	Max temperature and burn residence time (and total heat) determined from thermocouple data. Biomass reduction calculated as the difference between absolute

		pre- and post-burn weight, and combustion completeness (percentage of pre-burn mass consumed). Moisture content was calculated as the difference between fresh and dry biomass. These derived variables were determined overall and separately for *Calluna* and litter fractions. Bray-Curtis dissimilarities between measured variables revealed that fire characteristics and biomass measurements were as great or greater within than between burns.
Results		Maximum temperatures recorded were 982°C and 993°C at base and canopy, respectively. Burn residence time ranged from 11-547 seconds at the base and 6-474 seconds at the canopy. Combustion was incomplete in all burns. Up to 93% of total dry biomass was removed (mean 66%, range 21-93%) and up to 96% and 97% of litter and *Calluna* dry biomass, respectively. Thus, there was considerable variation in fire characteristics and biomass measurements, by 1-2 orders of magnitude, which was greater within than between burns.
Notes	Limitations identified by author	"Further work is needed to elucidate the exact relationship between fire characteristics and fire severity (sensu Keeley, 2009)." All fires between mid-February and early May, mostly in March/April. As fire characteristics and biomass measurements were as great or greater within than between burns the relationship between biomass reduction and other measured variables could not be further investigated.
	Limitations identified by review team	See Harris *et al*. 2011b re the representativeness of the site and vegetation: it is probably towards the extreme end of blanket bog in terms of low species-richness, high *Calluna* dominance and high level of modification. It might have been useful to have characterised the *Calluna* growth phases and/or vegetation height of the stands which were burnt.
	Evidence gaps and/or recommendations for further research	See above.

	Sources of funding	Geoff Eyre, Mark Osborne, Heather Trust, Moors for the Future, Moorland Association, Royal Horticultural and Botanical Society of Manchester and the Northern Counties and the BiodivERsA FIREMAN program (NERC/Defra).

Evidence Table

Name of Evidence Review:	Natural England Uplands Evidence Review
Name of Review Topic:	What are the effects of managed burning on the maintenance and restoration of upland peatland biodiversity and the provision of ecosystem services?
Review Question(s)	What are the effects of managed burning on the maintenance and restoration of the characteristic floristic composition, structure and function of upland peatland habitats?

Study details	Authors	Harris, M.P.K., Gemmell, C., McAllister, H., Le Duc, M.G. & Marrs, R.H.
	Year	2006
	Aim of study	To determine whether cool burning has positive effects on upland moorland vegetation.
	Study design	Correlation - ?
	Quality score	2+
	External validity	EV +
Population and setting	Source population	North Peak ESA upland moorland
	Eligible population	Chronosequence of burns in 4 x 1km^2 units from each of Bamford (79 burns) and Howden Moors (103), managed using cool burn for 15yrs.
	Inclusion and exclusion criteria	Known burn history - 10 burns of different elapse times selected at random from each site: 10 quadrats selected at random from each burn for field survey.
	Setting	Upland moorland blanket and raised mire, post cool burn community is NVC types M19

		& M20.
Methods of allocation to intervention/control	Methods of allocation	2 geographically distinct sites using same burn management
	Intervention description	Cool burning of small areas undertaken over the last 15 years.
	Control/comparison description	Differences in community composition among burns of different elapse time for the 2 geographic sites.
	Sample sizes	100 quadrats (10 per burn, 10 distinct burns) at each of 2 sites.
	Baseline comparisons	None – no pre-burn data obtained
	Study sufficiently powered	Fully randomised design for maximum statistical rigour. Adequate statistical testing applied during exploratory ordination as well as subsequent constrained ordinations and derived models. Multivariate analysis – implicit exploration of all factors & their inter-relationships
Outcomes and methods of analysis (inc effect size, CIs for each outcome and significance)	Primary outcome measures	% cover of species, litter, dung & bare ground Physical status of Calluna – stick versus bush growth (rationale not explained) Environmental variables – easting & northing, elapsed time since burn, vegetation height, slope, aspect, elevation, soil pH, soil LOI
	Secondary outcome measures	None
	Follow-up periods	Covers burns up to 15yrs elapse time, when cool burning was first introduced
	Methods of analysis	TABLEFIT for overall vegetation type per site, using full data set from 100 quadrats Initial use of Detrended Correspondance Analysis (ordination) with fitting of

		environmental variables and Monte Carlo simulation Linear Redundancy Analysis for constrained axes, followed by step wise modelling and variance partitioning to explore constrained ordinations. HOF modelling of species niche characteristics using GRAVY & gaussian error structure
Results		NVC types M19 at Bamford, M20 at Howden – degree of fit not provided Partial separation of 2 moors on DCA, for which there significant effects of measured environmental factors (4 x $P<0.001$, 3 x $P<0.01$, 2 x $P<0.05$)) Constrained RDA showed elevation, northing, elapse time, litter & bushy Calluna cover influence community composition ($P < 0.001$) Explanatory power is weak but additive for elapse time and elevation: correspondingly, unknown variables have much greater influence. HOF models identified significant relationships between individual species and the above 2 factors (no P-values provided): 2 species with a positive relationship with elapse time (*Calluna* and *Deschampsia flexuosa*) and 4 with a negative relationship. 8 species with a negative relationship with elevation and 3 with a positive relationship.
Notes	Limitations identified by author	Field survey limited by time spent on preparing GIS system and subsequent selection of sampling points. No comparable areas of hot burn within the same sites to determine the relative impact of two burn types. Usual limitations of space-for-time studies.
	Limitations identified by review team	No pre-burn baseline to determine the rapidity with which cool burn sites return to the pre-burn state or how much cool burning alters the community initially.

		Cool burning had only been used for ca. 15 yrs at the time of the study so the time frame is limited.
	Evidence gaps and/or recommendations for further research	Longer term study including repeat-burn sites Controlled experimental burning using a factorial/nested statistical design for maximum explanatory power.
	Sources of funding	Moors for the Future, G. Eyre

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Name of Evidence Review:	Natural England Uplands Evidence Review
Name of Review Topic:	What are the effects of managed burning on the maintenance and restoration of upland peatland biodiversity and the provision of ecosystem services?
Review Question(s)	a) flora/habitat.

Study details	Authors	HARRIS *et al*. [Also Harris 2011.]
	Year	2011b
	Aim of study	To examine the effect of management burns on plant community composition using a chronosequence from five Peak District blanket bog sites.
	Study design	2: chronosequence/site comparison.
	Quality score	2+
	External validity	EV+
Population and setting	Source population	Dark Peak blanket bog.
	Eligible population	Burn patches of different age classes including not recently burnt on five chosen sites on Dark Peak blanket bog.
	Inclusion and exclusion criteria	Not given.
	Setting	Five species-poor *Calluna*-dominated, *severely modified*, *degraded blanket bog* sites in the Peak

		District (Dark/North Peak).
Methods of allocation to intervention/control	Methods of allocation	Patches of known age since last burn.
	Intervention description	Managed burning.
	Control/comparison description	A smaller number of not recently burnt stands/patches for c.35+ years.
	Sample sizes	1,010 quadrats (10/patch in 2006 and 4/patch in 207-08) in 34 patches from five sites over two (3 sites) or three years (2 sites). This appears to represent 3.5% of all burn patches on the sites (954) sampled.
	Baseline comparisons	NA
	Study sufficiently powered	Not reported.
Outcomes and methods of analysis (inc effect size, CIs for each outcome and significance)	Primary outcome measures	Individual species cover.
	Secondary outcome measures	Plant material harvested from central 0.25 m^2, dried and weighed. *Calluna* response to burning (bush/stick). Range of associated environmental variables.
	Follow-up periods	Patches up to 18 years since last burn apart from controls (c.35+ years).
	Methods of analysis	Multivariate analyses (DCA with variation partitioning for testing relationship between species and environmental variables with significance tested with ramdomisation test, and HOF modelling of post-burning species responses).
Results		*Calluna* was the only species to show an increase after burning (and with increasing vegetation

		height); all others showed an increase immediately after burning and then either decreased or showed a unimodal/skewed response. Most other species were restricted to vegetation <40 cm tall and up to 20-25 yr since burning probably as a result of increasing *Calluna* dominance. Species-richness declined (slightly from a low starting level) over time since burning and was lowest in the relatively small number of unburned (≥35 yr) stands. The environmental variables analysed explained 15.2% of the variation in species composition. When shared variation was removed, the amount of variation was explained by site (3.6%), production (2.2%), biotic (1.0%) and physical (0.5%) (all significant at $p < 0.0001$) factors. The authors suggested that to maintain the higher species richness in the post burn phase requires rotational burning to avoid *Calluna*-dominance, although with the exception of *Rubus chamaemorus* and some bryophytes, most of these species were acid grassland or heathland species rather than those characteristic of blanket bog.
Notes	Limitations identified by author	The results relate to species-poor, *Calluna*-dominated [blanket bog] vegetation and may not be representative of more species-rich, wetter moorland [blanket bog] vegetation. Impacts on wider ecosystem services are not included and little is known on some aspects of them. Though responses from the chronosequence seem consistent they need to be corroborated by long-term observational studies.
	Limitations identified by review team	Results are not discussed in the context of blanket bog vegetation and habitat (though most samples were on deep peat). Most of the species reported are not characteristic of blanket mire vegetation and in particular most of those showing a post-burn increase are acid grassland or heath rather than bog species. The chronosequence method in general has been criticised in some published reviews, though this is only briefly discussed in the paper. Despite limitations in terms of geographic distribution and representativeness of blanket bog more widely, more general implications/conclusions are made about moorland vegetation in general.
	Evidence gaps and/or recommendations for	See above. It would be valuable to apply the method more widely across the English blanket bog resource.

	further research	
	Sources of funding	Geoff Eyre, Mark Osborne, Heather Trust, Moors for the Future, Moorland Association, Royal Horticultural and Botanical Society of Manchester and the Northern Counties and the BiodivERsA FIREMAN program (NERC/Defra).

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Name of Review Topic:	What are the effects of managed burning on the maintenance and restoration of upland peatland biodiversity and the provision of ecosystem services?
Review Question(s)	b

Study details	Authors	Haworth & Thompson
	Year	1990
	Aim of study	To determine environmental features associated with breeding bird distributions
	Study design	2: Quantitative experimental
	Quality score	2+
	External validity	EV+
Population and setting	Source population	UK upland heathland (peat deposits on plateaux)
	Eligible population	N England - Pennines - dominant vegetation types - vaccinium/calluna/eriophorum/empetrum/pteridium/molinia/nardus
	Inclusion and exclusion criteria	Moorland sites with presence of breeding birds and gamekeepering
	Setting	S. Pennines moorland (Yorkshire/Lancashire boundary)
Methods of allocation	Methods of allocation	N/A

to intervention/control	Intervention description	Gamekeepering
	Control/comparison description	Comparison between intensity of gamekeepering
	Sample sizes	618 0.25km squares
	Baseline comparisons	N/A
	Study sufficiently powered	Reasonable sample size, but not replicated
Outcomes and methods of analysis (inc effect size, CIs for each outcome and significance)	Primary outcome measures	Presence of breeding birds
	Secondary outcome measures	N/A
	Follow-up periods	N/A
	Methods of analysis	Discriminant function analysis used to compare 0.25km squares with and without breeding birds with variables (including gamekeepering intensity)
Results		Gamekeepering was associated with the presence of 3 wader species, but the significance was weak compared with topography. Areas subject to intensive gamekeepering were favoured by golden plover. Breeding redshank and curlew favoured intensively keepered areas. Short-eared owl and merlin showed a net preference for intensively keepered moor. Raptors may also have shown some preference for parts of the study area frequented by gamekeepers
Notes	Limitations identified by	N/R

	author	
	Limitations identified by review team	Study looks at correlation between presence of birds/gamekeepering intensity, but does not attempt to identify causality. The extent to which the association with gamekeepering is related to burning rather than predator control is not explored.
	Evidence gaps and/or recommendations for further research	Model population and assemblage responses to changes in land management
	Sources of funding	NCC

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Review Question(s)	What are the effects of managed burning on the maintenance and restoration of the characteristic floristic composition, structure and function of upland peatland habitat?

Study details	Authors	Hobbs, R.J. [Pt (summary) of long-term vegetation monitoring of the Hard Hill burning and grazing expt. At Moor House NNR all treated as one study.]
	Year	1984
	Aim of study	To investigate the effect of burn rotation time on community composition in high altitude *Calluna-Eriophorum* blanket mire.
	Study design	1: Randomised (partially) Control Trial
	Quality score	1+ [However, note evaluated with all other publications on the vegetation studies of the Hard Hill burning and grazing expt. at Moor House NNR and the study was classed overall as 1++. See the review report for more information on the other studies: Rawes & Williams (1973), Rawes & Hobbs (1979), Hobbs & Gimmingham (1980), Hobbs (1981), Hobbs (1984), Adamson & Kahl (2003)/Adamson pers. comm. (2004) to Stewart *et al*. (2004) and Lee *et al*. (2013).] [See also ET for Adamson & Kahl 2003.]
	External validity	EV+ (On balance the lack of statistical data analysis in this publication restricts its applicability, though stats are provided in subsequent publications from the expt which it was assessed with. The only rigorous data in the paper are for initial floristic

		composition and *Calluna* shoot lengths.)
Population and setting	Source population	North England, North Pennines, Cumbrian uplands
	Eligible population	*Calluna-Eriophorum* blanket mire
	Inclusion and exclusion criteria	Area within defined long term experimental plots Grazing pressure – grouse plus low density of sheep
	Setting	Moor House NNR
Methods of allocation to intervention/control	Methods of allocation	Pre-defined burning treatment in grazed section of 4 replicate long-term experimental plots: 2 x Burn treatments plus no burn randomised within each block
	Intervention description	10yr burn rotation - 3rd burn in 1975 20yr burn rotation – 2nd burn in 1975
	Control/comparison description	No burn – burnt in 1954 only
	Sample sizes	Design = 4 x blocks (replicates) x 2 treatments (10 & 20yr rotation) 1961 categorical abundance data (data for 7 key species presented): (4x2) x 25, 1mx1m quadrats = 200 1972 % cover data for all species determined from 100 pins (10 x 10-pin frame): (4x2) =8 1978-1980 inclusive, % frequency data for all species: (4x2) x 128, 10cmx10cm quadrats (recording +/- data) = (4x2x1) = 8

		Terminal Shoot lengths of *Calluna*: 1976: 2 blocks x 2 treatments x 50 shoots = 200 1977: 2 blocks x 2 treatments x 100 shoots = 400 1978-1980: 4 blocks x 2 treatments x 100 shoots = 800 Shoot weight determined in 1979 for 4 x 2 x 100 shoots = 800
	Baseline comparisons	Design = 4 x blocks x 1control 1961 categorical abundance data (data for 7 key species presented): (4 x 1) x 25, 1mx1m quadrats = 100 1972 % cover data determined for all species from 100 pins (10 x 10-pin frame): (4x1) = 4 *DATA NOT PRESENTED* 1978-1980 inclusive, % frequency data for all species: (4x1) x 128, 10cmx10cm quadrats (recording +/- data) = 4 *DATA NOT PRESENTED* Terminal Shoot lengths of *Calluna*: 1976: 2 blocks x 50 shoots = 100 1977: 2 blocks x 100 shoots = 200 1978-1980: 4 blocks x 100 shoots = 400 Shoot weight determined in 1979 for 4 x 1 x 100 shoots = 400
	Study sufficiently powered	1961 categorical abundance data adequate for assessing degree of initial floristic heterogeneity among treatments & blocks % Cover data in 1972 & % frequency data for 1978-1980 are weak – limited to a single figure per plot

		Terminal shoot length data (and weight data for 1979) adequate but unbalanced
Outcomes and methods of analysis (inc effect size, CIs for each outcome and significance)	Primary outcome measures	1961 – categorical cover value (Domin scale) 1972 - % cover 1978-1980 - % frequency Terminal shoot lengths of *Calluna* (cm)
	Secondary outcome measures	1961: mean Domin value (of 25 quadrats) per plot (for each of 7 key species) summed across 3 treatments (2 burns & no burn) for each replicate block (because treatment effect was not significant) 1978-1980: No. of species of each of vascular plants, bryophytes & lichens and overall total no. of species.
	Follow-up periods	Identical between burnt & unburnt plots: 6 yrs since initial burn for 1961 abundance data 17yrs since initial burn for 1972 data (7 yrs since 2^{nd} burn for 10yr rotation) 21yrs since initial burn for 1976&1977 shoot data: 1-2yrs since last burn for both burn treatments (3^{rd} burn for 10yr rotation, 2^{nd} burn for 20yr rotation) 23 yrs since initial burn for 1978-1980 floristic & shoot data: 3-5yrs since last burn for burn treatments (3^{rd} burn for 10yr rotation, 2^{nd} burn for 20yr rotation)
	Methods of analysis	Factorial ANOVA for 1961 Domin data ANOVA for shoot lengths – no details provided Correlation (no details) between shoot lengths & weights for 1979 data

		No statistical treatment of % cover data for 1972 or % frequency data from 1978-1980
Results		There were significant differences among replicate blocks for 5 of the 7 key species in 1961 (N.B. not *Eriophorum vaginatum*), indicating initial spatial heterogeneity. *Calluna* was less abundant in Block A compared to B-D ($p<0.05$). % cover data 1972: *Calluna* consistently higher in 20yr burn (no statistical analysis); the more common bryophytes (*Campylopus paradoxus, Lophozia ventricosa, Pohlia nutans*) had lower cover in the 20yr burn plots. *Eriophorum* spp. & *Rubus chamaemorus* showed no clear trends % frequency data 1978-1980 *Eriophorum vaginatum* dominated all plots in the early post-fire period; *E. angustifolium* was co-dominant *Calluna* showed a progressive increase from 1978-1980 and was more frequent in the 20yr rotation in all but block C. *Campylopus paradoxus* & *Lophozia ventricosa* were more frequent in the 20yr rotation. *Calluna* shoot length & weight were +ively correlated ($r=0.938$, $p<0.001$) Shoot growth reduced progressively over the 1st 1-5yrs after a burn. Shoot lengths were significantly longer in the 10yr rotation in the first year following burning; by the 3rd year the difference was not significant.
Notes	Limitations identified by author	Differences in pre-burn vegetation had a pronounced effect on post-fire vegetation development.

	Limitations identified by review team	Use, without due justification, of permanent transects for % frequency recording from 1978-1980, exacerbating any initial differences in spatial patterning. No indication that plants targeted for shoot collection were discounted in subsequent sampling events. No discussion of standardisation of 'burning' as a treatment or its comparability to larger scale burns. Lack of statistical analysis of cover and frequency data No consideration of the possible role of grazers in modifying the post-burn response of *Calluna*. Possible effect of initial composition on burn characteristics via differences in fuel load and type - could in theory generate a +ive feedback system
	Evidence gaps and/or recommendations for further research	Clarify results using sampling design conducive to rigorous statistical analysis and consider community responses by using multivariate analysis. Results could be compared usefully to those within the central climatic and altitudinal range for *Calluna*. The importance of grazing as a modifying factor is relevant to many upland scenarios.
	Sources of funding	Not acknowledged – need to reference original thesis.

Hobbs (1984) studied the effect of burn rotation time on the regrowth of *Calluna* in high altitude *Calluna-Eriophorum* blanket mire, using the long term experimental plots at Hard Hill, Moor House NNR. The factorial design is partially randomised with four replicate blocks and three levels of burning: no repeat burning after the initial site-wide burn in 1954 ('unburnt'); 10 year rotation time with burns in 1965 and 1975; and a 20 year rotation time with the second burn in 1975. Grazing is an additional factor (present/absent) which was not considered in this study.

Hobbs supplemented the study with data sets from 1961, 1972 and 1976-77. In 1961, a categorical measure of abundance was derived from 25 randomly located 1mx1m quadrats and the results provided for 7 key species: differences among the four blocks were compared using ANOVA. In 1972 the total hits for all species on 10 randomly located 10-pin frames were enumerated for each plot to provide a single value of % cover. From 1978-1980, % frequency of all species was determined from presence/absence in 128, 10x10cm quadrats located systematically along a single 12.8m permanent transect in each plot. No statistical analysis was presented for data sets from 1972 and 1978-1980.

Shoot lengths of *Calluna* were determined in successive years from 1976 to 1980; only 2 blocks were sampled in 1976 & 1977 whereas all 4 blocks were included from 1978-1980. Initially, 50 shoots were collected but this was increased to 100 for the years 1977-1980. In the first year after burning (1976) shoot lengths were significantly greater in the 10yr rotation and those from the 20yr rotation were greater than in control plots: three years after the burn these differences were insignificant. Shoots weights were also determined in 1979, which showed a significant positive correlation with length for that year.

The composition of the experimental plots is heterogeneous initially and this has a marked effect on the response to burn treatment. The results indicate that burning favours *Calluna* only initially, i.e in the very short-term (1-2 years), because of the subsequent and rapid re-growth of *Eriophorum vaginatum*, which comes to dominate for ca. 10 years.

Burning with the objective of improving *Calluna* availability is unlikely to be appropriate to high altitude *Calluna-Eriophorum vaginatum* blanket mire because *Calluna* appears to achieve a ‘steady state’ naturally through the continuous layering and rejuvenation of stems among the Sphagnum carpet. Instead, repeated burning is likely to favour dominance by *Eriophorum* , which is preferred by sheep during summer.

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Review Question(s)	What are the effects of managed burning on the maintenance and enhancement of the characteristic fauna of upland peatlands either directly or indirectly through changes in vegetation composition and structure?

Study details	Authors	Hochkirch, A & Frauke, A
	Year	2007
	Aim of study	To test the hypotheses that fire affects Orthoptera abundance and that the effects wildfire are greater than those of planned burning.
	Study design	Correlation
	Quality score	2++
	External validity	EV-
Population and setting	Source population	Raised mires in NW Germany.
	Eligible population	Areas burned in winter/spring 2003 by planned burn or wildfire.
	Inclusion and exclusion criteria	Opportunistic – restricted to areas burned in 2003. Sample transects within and adjacent to burned areas chosen as ‘homogenous’.

	Setting	Raised bog peatlands in NW Germany – sites managed for nature conservation.
Methods of allocation to intervention/control	Methods of allocation	Four sites – 2 with prescribed burns 2 with wildfire. Within burn areas sample transects located in homogenous areas. Comparators in unburned vegetation parallel to the edge of the burned area 50m from burn edge. In addition transects were sited centered on and at right angle to the burn edge.
	Intervention description	Planned burns (2 sites) and wildfire(2 sites).
	Control/comparison description	Differences in vegetation and Orthoptera fauna along transects within burn areas and in adjacent unburned areas.
	Sample sizes	Four sites with 2-6 transect samples (50m) in burned areas (8 in planned and 8 in wildfire) and 2 transects in unburned area at each. 12 additional transects across the burn edge. Orthoptera sampled 3 times (July – September). Vegetation sampled for each 10m section of transects.
	Baseline comparisons	None – no pre burn data obtained.
	Study sufficiently powered	Sample locations not randomised Multivariate analysis (ANOVA) of variables (burned/unburned, fire type, census date, site). NMDS Ordination of Orthopteran assemblage.
Outcomes and methods of analysis (inc effect size, CIs for each outcome and significance)	Primary outcome measures	Measures of Orthopteran assemblage (species richness and numbers of each) in sample areas and comparators. Plant species abundance and measures of vegetation structure.
	Secondary outcome measures	Response of vegetation to fire and correlation between Orthoptera and vegetation.

	Follow-up periods	None.
	Methods of analysis	Multivariate analysis (ANOVA) of variables (burned/unburned, fire type, census date, site). NMDS Ordination of Orthopteran assemblage.
Results		The data collected do not support the hypotheses that burning affects abundance or that the effects of wildfire are different from those of controlled burning. Vegetation structure is the main determinant of Orthopteran species assemblage. Differences in Orthoptera assemblage were greater between bog areas than between fire treatments. The study suggests that Orthoptera do not recolonise from unburned areas but may colonise by dispersal or survive in situ. For one threatened species burning seems to be beneficial.
Notes	Limitations identified by author	Unequal sampling of treated areas and comparators. Unusual weather during the sample period? Interventions restricted to the period when Orthoptera are inactive (effect of wildfires in summer?).
	Limitations identified by review team	Sample locations not randomised and unequal sampling of treated areas and comparators. Differences between sites may confound differences of treatment.
	Evidence gaps and/or recommendations for further research	Assess sites before and after fire. Follow up of burn sites to show temporal change in the assemblage as vegetation recovers. Controlled experimental burning.

	Sources of funding	University of Osnabruck.

Evidence Table

Name of Evidence Review:	Natural England Uplands Evidence Review
Name of Review Topic:	What are the effects of managed burning on the maintenance and restoration of upland peatland biodiversity and the provision of ecosystem services?
Review Question(s)	(c) What are the effects of managed burning of upland peatlands on carbon sequestration and storage, either directly or indirectly through changes in vegetation composition and structure? d) What are the effects of managed burning of upland peatlands on water quality (including colouration, release of metals and other pollutants and aquatic biodiversity) and water flow (including downstream flood risk), either directly or indirectly through changes in vegetation composition and structure?

Study details	Authors	Holden, J.
	Year	2005a
	Aim of study	To examine whether there are any general associations between surface vegetation species and piping.
	Study design	Primarily Observational correlation study but also a section of Experimental
	Quality score	2+
	External validity	EV+
Population and setting	Source population	Upland blanket bog peat catchments
	Eligible population	160 upland blanket bog peat catchments across Britain (catchments chosen

		systematically so that areas of British blanket bog were representatively sampled).
	Inclusion and exclusion criteria	Only those between 0.8km^2 and 4.2km^2 in area. Majority of study on deep peat (0.5-8m deep).
	Setting	Study 1: 160 British upland blanket bog peat catchments. Study 2: Moor House, North Pennines. Study 3: Experimental study using peat blocks from Moor House.
Methods of allocation to intervention/control	Methods of allocation	Study 1: Correlational study with catchments chosen systematically so that areas of British blanket bog were representatively sampled. No details about selection of plots within catchments provided. Study 2: Plots with *Calluna* compared with plots without *Calluna* (p/a of *Calluna* related to altitude) Study 3: For experimental part of study, 12 blocks from three vegetation types and bare ground (48 blocks in total), each split into two, with one half receiving treatment. Only recently colonised *Calluna* plots used.
	Intervention description	Study 1: P/A of three vegetation types and/or bare ground on plot. Study 2: P/A of *Calluna* Study 3: Rainfall
	Control/comparison description	Study 1: Correlational study comparing pipe frequency (from ground penetrating radar GPR surveys) with p/a of vegetation type and bare ground. Study 2: Frequency of pipes from plots with *Calluna* compared with plots without *Calluna* (p/a of *Calluna* related to altitude) (topographic index same for each plot). Study 3: For experimental part of study, blocks split into two and half received

		treatment (heavy rainfall).
	Sample sizes	Study 1: 160 catchments, with 6 survey plots in each catchment. Study 2: 32 plots within Moor House Reserve Study 3 (experimental): 48 peat blocks, each split into two, one block of pair then receiving treatment.
	Baseline comparisons	Not applicable
	Study sufficiently powered	No power analysis but statistics and sample sizes adequate.
Outcomes and methods of analysis (inc effect size, CIs for each outcome and significance)	Primary outcome measures	Pipe frequency (from ground penetrating radar GPR surveys)
	Secondary outcome measures	Macropore flow (in Study 3: experimental)
	Follow-up periods	Study 3: 140 days follow up after 10 years worth of rainfall.
	Methods of analysis	Study 1: ANOVA Study 2: Mann-Whitney U Test Study 3: ANOVA and paired t-tests
Results		Study 1: *Calluna*-covered peats and peats with a bare surface tend to have a significantly higher frequency of soil piping ($p<0.001$) than peats without these cover types. No significant relationship between topographic index and pipe frequency. Study 2: Significantly more piping on hillsides below 650m in altitude where *Calluna* present than those at higher altitudes where *Calluna* was not present ($p=0.0008$). Results controlled for effects of topographic index, aspect, slope, underlying geology,

		peat depth and water table. NB paper points out possible that warmer summer temperatures on lower plots could make these plots more susceptible to dessication and hence cracking and pipe initiation. Study 3: The proportion of macropore flow was much greater on the peat blocks subject to rainfall treatment only in the case of those covered with *Calluna* (P<0.002), ie the only peat to have developed macropores and small pipes (>2mm) during the experiment was under a young *Calluna* cover. Bare peat blocks did not suffer increased piping under experimental high rainfall conditions. This may be because they had had their top layers removed prior to the study starting and therefore there was no initial dessication. Author suggests that surface dessication during dry summer periods could be a pre-requisite for pipe development in bare peat.
Notes	Limitations identified by author	Study 1: GPR cannot detect pipes smaller than 10cm in diameter. Study 2: paper points out that it is possible that warmer summer temperatures on lower plots (which had *Calluna* cover) could make these plots more susceptible to dessication and hence cracking and pipe initiation. Study 3: Possible that increase in water conduction through macropores under colonising *Calluna* (detected in lab study) is predominantly in the vertical direction, whereas soil pipes drain hillslopes in predominantly lateral direction. Also lab studies imitating 10 years of rainfall may not be representative. Also lab study looked at upper 30cm of peat and not clear how this affects pipe formation deep down. Generally results contrast with Maesnant study in Wales (Jones et al. 1991) where pipes only found in *Calluna* free areas but this was in podzols soils. Holden notes that the relationship between pipe frequency and vegetation type may differ in other soil and peat types (this study focused on deep peat). Results of main study (study 1) could be explained by better drainage as a result of piping encouraging *Calluna* growth. While author notes that the results of the Moor

		House study (study 2) and experimental study (study 3) suggest that *Calluna* is a causal factor in increased pipe frequency, he does note that there may be both a cause and effect relationship.
	Limitations identified by review team	Since vegetation classification methodology not detailed, it is not clear how frequent *Calluna*/bare ground need to be to have an effect on pipe frequency. Another paper (Holden 2005b – see below) demonstrated that piping was more frequent in survey plots with moorland gripping . However, this variable was not controlled for here and could have been a confounding factor. No direct examination of effects of burning (except through indirect effects on extent of bare ground and vegetation cover).
	Evidence gaps and/or recommendations for further research	As above.
	Sources of funding	?

Haldon, J. (2005b) Controls of soil pipe frequency in upland blanket peat. Journal of Geophysical Research: Earth Surface, 110 .

This paper is referred to in the paper reviewed above. It is assumed to use the same dataset, from 160 British blanket peat catchments (6 survey plots/catchment). The frequency of soil pipes in the 160 plots was evaluated using ground penetrating radar, and the influence of land management (moorland gripping), topographic position, slope gradient and aspect on the frequency investigated using GLM. Soil pipes were detected in all 160 catchments with a mean of 69.2 per km of GPR transect.

Pipe frequency varied according to the topographic position of the survey plot, with topslopes having greater pipe frequencies than footslopes, which in turn had greater pipe frequencies than midslopes (ANOVA, $P<0.001$). Pipe frequency was not related to slope angle or to topographic index, however. Gripped hillslope plots ($n=171$) had significantly more soil pipes than non-gripped plots ($n=789$) (GLM, $P<0.001$), and this was independent of the effect of wetness (pipes were more frequent in very wet areas >2000mm/year). Peat depth was weakly positively correlated (p=0.035) with pipe frequency. Since topslopes and footslopes tended to have deeper peat, this may partly explain why topographic position affected pipe frequency. However, the relative structure of the peat down the slope may have been more important - the structure of the peat on topslopes was more variable and was thus considered more conducive to pipe development. While aspect was not a significant factor in general, there was a significant interaction with precipitation: southwesterly facing slopes in drier catchments tended to have more piping.

The biggest factor determining pipe frequency was the presence/absence of gripping. The author argues that gripping results in increased drying of the peat and enhanced crack development and thus promotes conditions conducive to pipe development. While it was not possible to verify that pipe densities were not already high on plots before they were gripped, the data suggests that this was not the case.

Evidence Table

Name of Evidence Review:	Natural England Uplands Evidence Review
Name of Review Topic:	What are the effects of managed burning on the maintenance and restoration of upland peatland biodiversity and the provision of ecosystem services?
Review Question(s)	

Study details	Authors	HOLDEN *et al*.
	Year	2013
	Aim of study	To study infiltration, saturated hydraulic conductivity and macropore flow in *deep peat* on moorlands in the Pennines. Measurements were performed on: unburnt peat; where prescribed burning had taken place 2, 4 (both 'recent burn' treatments) and >15 years prior to sampling; and where a wildfire had taken place four months prior to sampling. Important flowpaths in the upper layers of blanket peat and were investigated through the use of tension disk infiltrometers.
	Study design	1: control trial on management burns and (an unplanned) 'wildfire'.
	Quality score	1+
	External validity	EV+
Population and setting	Source population	Pennine moorland subject to rotational burning.

	Eligible population	Unburnt and burnt patches of different ages on five sites.
	Inclusion ~~and exclusion~~ criteria	Blanket peat >1 m deep, subject to light sheep grazing (none November-February). Subject to rotational burning apart from one unburned control site and one subject to a wildfire.
	Setting	Five sites in the Peak District/North Pennines.
Methods of allocation to intervention/control	Methods of allocation	NR re sites. Within sites patch locations chosen with respect to a topographic index to control for slope and drainage length as they have been shown to control the proportion of flow through macropores. Each site had one patch with low, mid and high topographic index settings.
	Intervention description	Managed burning (different ages, 2, 3-4, 15-25 yr post-burn and a wildfire at each of five sites).
	Control/comparison description	Unburnt site and wildfire.
	Sample sizes	Three patches of c.400 m^2 at each of five sites.
	Baseline comparisons	NA
	Study sufficiently powered	NR, but 15 patches across five widely distributed sites (through three relatively close together).
Outcomes and methods of analysis (inc effect size, CIs for each outcome and significance)	Primary outcome measures	Infiltration measurements, effective macroporosity and saturated hydraulic conductivity.
	Secondary outcome measures	Infiltration rate, proportion of flow moving through macropores and soil properties.

	Follow-up periods	Up to 25 yr post-burn (as chronosequence with all assessments in July-August 2011).
	Methods of analysis	Significance testing included: t-tests, Turkey's post-hoc tests, F-tests, box and whisker plots.
Results		Where there had been recent burning (<2yr, <4yr and wildfire site) saturated hydraulic conductivity was approximately three times lower than where there was no burning or where burning was last conducted >15 years ago. The contribution of macropore flow to overall infiltration was significantly lower (between 12 and 25 % less) in the recently burnt treatments. There were no significant differences in saturated hydraulic conductivity or macropore flow between peat which had been subject to recent wildfire and those which had undergone recent prescribed burning (<2 and <4 yr). The results suggest fire influences the near-surface hydrological functioning of peatlands but that recovery in terms of saturated hydraulic conductivity and macropore flow may be possible within two decades if there are no further fires. Fire reduces the role of micropores and therefore increases the role of micropores in infiltration and percolation of water and may therefore increase the potential for leaching of dissolved organic carbon because there would be increased contact time between the water and peat. Possible mechanisms for the effect of burning on macropores are the production of fine sediment and ash which block macropores.
Notes	Limitations identified by author	Need for more work on overland flow and effects on (clogging) macropores by infiltrometer experiment before and after ash addition. Three of five sites relatively close together.
	Limitations identified by review team	
	Evidence gaps and/or recommendations for further research	Extension of studies to more sites (although it is recognised that this is one of the first papers from the EMBER project and that there will be more to follow).

	Sources of funding	NERC (as part of the Leeds University EMBER project).

Evidence Table

Name of Evidence Review:	Natural England Uplands Evidence Review
Name of Review Topic:	What are the effects of managed burning on the maintenance and restoration of upland peatland biodiversity and the provision of ecosystem services?
Review Question(s)	What are the effects of managed burning of upland peatlands on water quality (including colouration, release of metals and other pollutants and aquatic biodiversity) and water flow (including downstream flood risk), either directly or indirectly through changes in vegetation composition and structure?

Study details	Authors	Holden, J., Chapman, P.J., Palmer, S.M., Kay, P. & Grayson, R.
	Year	2012 (also 2011 report)
	Aim of study	To appraise critically studies ostensibly exploring the relationship between water colouration and/or DOC concentration and the managed burning of upland peatland and to reconcile apparent contradictions among three different scales of study.
	Study design	Critical synthesis/review
	Quality score	2++
	External validity	EV+
Population and setting	Source population	Primarily upland peatland, but minority from dry heath sites with podzolic soils
	Eligible population	Examples of burning dwarf shrub
	Inclusion and exclusion criteria	Studies that relate water chemistry to burning, at any scale

	Setting	UK (primarily North England) + 1 study from Brittany (not peatland)
Methods of allocation to intervention/control	Methods of allocation	Laboratory studies using cores either constructed and manipulated in situ or removed from burnt sites (lysimeters) Plot based studies, primarily of long-term experimental sites where different burn cycles have been applied. Catchment scale studies
	Intervention description	Controlled burning mostly, but some wildfires ('hot' burns – may be induced experimentally) also included for comparison.
	Control/comparison description	Unburnt cores/plots/catchments/streams within individual catchments Catchments for which aerial photographs at discrete time intervals are used to enumerate: the total area of land evidenced as burnt ; the area of recently burnt ground (still within *Calluna* pioneer stage)
	Sample sizes	5 laboratory-based (could be 4 as one is described ambiguously as being lab from 'field blocks' 8 plot-based studies – 6 of which are based at Hard Hill (see issues identified in summary) & 2 not on peatland 9 catchment-scale but varied scales: multiple streams within 1 catchment; multiple sub-catchments; multiple catchments within a region
	Baseline comparisons	Unburnt & hot versus cool burn cores/soil samples Burnt versus unburnt plots & different burn cycles Catchments/streams/sub-catchments experiencing different intensities of burning (proportion of land burnt or proposed as within pioneer age class)

	Study sufficiently powered	Appraisal limited by the relatively small amount of available literature. Plot-based studies are dominated by those on the Hard Hill burning site at Moor House NNR (6 of the 8, and representing all of the peatland examples). The validity of hydrological studies from the 4 replicate blocks is questioned (issues of hydraulic connectivity and inappropriate depth of sampling) but the appraisal still draws on results from these 6 investigations.
Outcomes and methods of analysis (inc effect size, CIs for each outcome and significance)	Primary outcome measures	Did the study demonstrate a +ive or –ive impact of burning on (i) water colour and/or (ii) DOC Scale of study – core/plot/catchment Basic investigative approach Key outcomes of each study (specific water parameters or other variables – e.g. water table depth)
	Secondary outcome measures	
	Follow-up periods	Study dependent – part of the critique considers the time scale over which critical changes may occur after burning and whether or not individual studies are capable of detecting these.
	Methods of analysis	Critique – no data re-interpretation Some published data are used to illustrate the magnitude of DOC required in water outflow from managed burns if these are solely responsible for observed trends in catchment-scale DOC.
Results		Lab-based studies suggest that colour increases after burning but that this may be transient

		Plot-based studies (strongly biased by use of the Hard Hill site) suggest a possible transient release of colour but no changes in DOC The majority (but not all) of catchment based investigations indicate strong (but not necessarily causal) relationship between increased incidence of burning and increased colour/DOC concentration.
Notes	Limitations identified by author	Limited trawl of relevant literature Difficulties of data from the Hard Hill site – potential hydraulic connectivity; inappropriate sampling depths; use of a site at altitudinal/climatic limit for *Calluna*, which would have higher growth rate at warmer sites. Disparity in the manner in which colour and DOC have been measured, and the legitimacy of using proxy measures and/or ratios. Appropriateness of comparing studies of peatland systems with those for skeletal/podzolic soils.
	Limitations identified by review team	Do not acknowledge any role of grazing in catchment dynamics. How has grazing pressure and the proportions of different grazing stock changed over the time period under consideration? Could grazing act as a modifier?
	Evidence gaps and/or recommendations for further research	Improved understanding of the hydraulic linkage between burnt areas and collecting streams Clarification of the behaviour of DOC within water, from its origin to its presence in outflow streams and the pathways between The contribution that vegetation makes to DOC and the role of above and below ground processes. The behaviour of DOC among heather age classes. Clarification of the potential role of grazing in the vegetation/DOC relationship

	Sources of funding	Yorkshire Water Services Ltd.

Summary

Holden et al. (2012) present a critical appraisal of studies ostensibly exploring the relationship between water colouration and/or DOC concentration and the managed burning of upland peatland. Both variables affect drinking water quality with significant cost implications for the water service industry in complying to statutory requirements, irrespective of health issues.

The authors aim to reconcile apparent contradictions among three scales of published study: laboratory-based studies using core samples removed from burnt sites in which percolates are analysed (i.e. lysimeters); hydrological studies within plots subject to experimental burning (but designed originally for ecological study); and catchment scale studies based on water quality data collected primarily by the water service industry. The critical time frame for detecting changes in both variables change is discussed.

The ways in which water colour is determined is considered as is its relationship to DOC and the use of ratios to denote the relationship; any inter-study comparison must identify clearly the parameters quantified as well as their legitimacy. Furthermore, to elucidate the response of DOC to burning at the catchment scale, only the portion of the hydrological flux that contributes to stream flow should be sampled. The balance of empirical evidence suggests that water movement below the top 5-10cm of the peat layer may be irrelevant.

Plot scale studies have failed to confirm that burning results in increased water colour/DOC. Two studies did not relate to peat soils and 6 of the 8 investigations utilised the permanent plots on the Hard Hill burning site within Moor House NNR. Significant potential problems have been identified with this site:

(i) there is potential hydraulic connectivity among the four replicate blocks because of their relative positions on a sloping hillside;

(ii) regular trampling over many years in and around the plots may have altered soil structure and function;

(iii) it is difficult to standardise small-scale controlled burning, which may not achieve the same fire characteristics as larger stands;

(iv) bulk-sampling of water from excessive depths of peat (to 90cm) may obfuscate the critical processes if these are indeed limited to the top 5-10cm of the peat layer.

In general, catchment scale studies support the proposition that increased burning over the last 10-15 years has prompted the recorded increases in water colour and DOC. However, Holden et al. demonstrate that if managed burning is the sole driver, DOC of the order 115-345mg l^{-1} m should be expected in water derived from what are only small burnt areas of ca. 2ha or less (scaled to reflect catchment-scale burn intensity) in order to generate the concentrations of DOC monitored in catchment outflow. This figure represents a conservative estimate based on the simplest possible hydrological relationship between water efflux from a burn and stream flow. None of the studies presented reported figures anywhere near this magnitude.

Holden et al. conclude that there is no empirical mechanistic evidence to support the assertion of a simple linkage between burning and increased water colour/DOC. There is increasing evidence that the catchment vegetation, and perhaps *Calluna* specifically (the target of managed burning), may be an influential factor. The authors emphasise that improved understanding of the hydraulic linkages within catchments and the fate of DOC on its pathway to the stream is essential if the mechanism driving changes in water quality is to be elucidated.

Evidence Table

Name of Evidence Review:	Natural England Uplands Evidence Review
Name of Review Topic:	What are the effects of managed burning on the maintenance and restoration of upland peatland biodiversity and the provision of ecosystem services?
Review Question(s)	d) water quality/colouration.

Study details	Authors	HOLMES *et al*.
	Year	1993
	Aim of study	A large-scale survey of ground beetles (*Carabidae*) in a total of 300 trapping stations in 118 *peatland* sites throughout Wales. Factors influencing the distribution of carabid beetles were investigated using ordination. Burning (categorised as recently burnt, burnt but not recently and not known to have been burnt) was one of the variables recorded, though little information is included on it in the paper.
	Study design	2: survey.
	Quality score	2-
	External validity	EV-
Population and setting	Source population	Welsh peatlands
	Eligible population	Welsh peatland sites

	Inclusion and exclusion criteria	NR
	Setting	Welsh peatlands
Methods of allocation to intervention/control	Methods of allocation	NA
	Intervention description	Burning (recent/not known in last 4 yr) as a variable.
	Control/comparison description	NA
	Sample sizes	300 trapping stations at 118 peatland sites sampled over three years 1987-89 (pitfall traps from 8-12 weeks in summer/autumn).
	Baseline comparisons	NA
	Study sufficiently powered	NA
Outcomes and methods of analysis (inc effect size, CIs for each outcome and significance)	Primary outcome measures	Numbers of individuals trapped identified to species by stations and overall.
	Secondary outcome measures	Ten environmental/management variables including recent burning (present/absent)>
	Follow-up periods	NA, but three year survey period.
	Methods of analysis	Ordination (DECORANA) of trapping stations and species. Ordination scores compared with ten environmental/management variables by correlation and stepwise regression and then a multiple regression. Effects of individual variables on axis scores were examined by one-way ANOVA.

Results		The most important factors identified were nutrient status and saturation of the substrate (which may be affected by burning), altitude and livestock grazing. Burning was also considered a significant factor but could not be investigated thoroughly because of insufficient data on timing, frequency and severity of burns.
Notes	Limitations identified by author	Only two categories of burning used (recent/not recent). The effects of burning are likely to be much more complex, with factors such as timing of burn, severity (related to prevailing weather conditions), years since burning, etc. all likely to be of importance.
	Limitations identified by review team	Need for a more meaningful classification of burning.
	Evidence gaps and/or recommendations for further research	
	Sources of funding	NCC.

Evidence Table

Name of Evidence Review:	Natural England Uplands Evidence Review
Name of Review Topic:	What are the effects of managed burning on the maintenance and restoration of upland peatland biodiversity and the provision of ecosystem services?
Review Question(s)	e

Study details	Authors	Kinako and Gimingham
	Year	1980
	Aim of study	To establish the magnitude of soil loss through burning, the effect of slope angle and the effect of vegetational recovery in reducing habitat deterioration
	Study design	Site comparison/correlation.
	Quality score	2+
	External validity	-
Population and setting	Source population	Upland dwarf shrub dominated communities
	Eligible population	Calluna-vaccinium habitats, with associated species, including Erica tetralix
	Inclusion and exclusion criteria	Sites with varying slope angle (flat, intermediate and steep)
	Setting	Upland heaths NE Scotland
Methods of allocation	Methods of allocation	Method of allocation not reported – one site burnt as part of regular burn cycle, second

to intervention/control		site burnt specifically for the study
	Intervention description	Burning – no details provided
	Control/comparison description	Study included no control/comparison – 2 study sites subject to same intervention
	Sample sizes	15 samples per burn area, 3 burn areas per study site (2 study sites)
	Baseline comparisons	Baseline measurements assumed to be '0', carried out 3 weeks post-burn
	Study sufficiently powered	No power analysis given. Replicated study (x2) but small sample sizes (15 samples per plot)
Outcomes and methods of analysis (inc effect size, CIs for each outcome and significance)	Primary outcome measures	Magnitude of soil erosion (expressed as mean depth (cm) and volume (m^3/ha))
	Secondary outcome measures	Vegetation recovery (recorded as frequency of rooted plants and height)
	Follow-up periods	18-24 months
	Methods of analysis	Figures for mean and net losses provided/ Vegetation recovery & loss of soil analysed through regression equations and correlation coefficients.
Results		Reductions in level of soil surface occurred at all sites (0.27-0.55cm). No consistent relationship with slope angle was identified. Initial rate of erosion positively correlated to slope (r=0.93) at Kerloch site only. A uniform pattern in relation to time was shown, with erosion reaching a maximum within 8 months of the burn, and complete stability restored after 15-20 months.

		Habitat deterioration though soil erosion was least where vegetation recovery was most rapid, although levels of significance varied (p=0.001 – p=0.05) Impact of soil loss may be greatest where large areas are burnt, precluding adequate restoration of material from surrounding areas.
Notes	Limitations identified by author	Some erosion may occur during the burn period (particularly through wind erosion), and this is not accounted for in the study
	Limitations identified by review team	Limited details on methodologies mean possible variables affecting outcomes are not easily assessed – e.g. intensity of burn
	Evidence gaps and/or recommendations for further research	Effect of climatic variables, particularly precipitation, on soil erosion magnitude Possibility of size effect identified by authors, quantification of this effect would be of interest
	Sources of funding	N/R

Evidence Table

Name of Evidence Review:	Natural England Uplands Evidence Review
Name of Review Topic:	What are the effects of managed burning on the maintenance and restoration of upland peatland biodiversity and the provision of ecosystem services?
Review Question(s)	a) flora

Study details	Authors	LINDSAY, R.A. & ROSS, S.Y. [Also Lindsay 1977.]
	Year	1994
	Aim of study	To study the effects of an extensive, severe wildfire in 1976 on vegetation at Glasson Moss, a previously *less modified lowland raised bog NNR* which is one of the sites in the South Solway Mosses NNR in Cumbria. Lindsay (1977) mapped the extend of the burn and vegetation types and sampled each with quadrats recording, in particular, *Sphagnum* presence, cover and damage from the fire, in 1977 flowing a previous survey before the fire in 1975. Lindsay & Ross (1994) describe the results of regular monitoring of recovery up to *c*.15 yr following the burn using fixed transects across the unburnt and burnt areas along which vegetation and surface topography were recorded and stereo photos taken.
	Study design	2: survey/monitoring of post-fire recovery.
	Quality score	2++
	External validity	EV+

Population and setting	Source population	Glasson Moss, South Solway Mosses NNR, Cumbria
	Eligible population	Mainly fire-damaged areas within the site.
	Inclusion and exclusion criteria	NA
	Setting	Glasson Moss, a previously *less modified lowland raised bog* which is one of the sites in the South Solway Mosses NNR in Cumbria. Though a lowland site, it was included in the review as it provides important information on *Sphagnum* recovery after fire on a high quality, *Sphagnum*-rich site.
Methods of allocation to intervention/control	Methods of allocation	NA
	Intervention description	Wildfire
	Control/comparison description	Pre-fire baseline (1975) and unburnt areas in 1977 and up to 15 yr post-burn.
	Sample sizes	8 transect 'isonomes'.
	Baseline comparisons	Pre-fire baseline (1975) and unburnt areas.
	Study sufficiently powered	NR
Outcomes and methods of analysis (inc effect size, CIs for each outcome and significance)	Primary outcome measures	Plant species presence/abundance in a contiguous block of 10 cm squares (isonomes) along transects (6 burnt and 2 unburnt), particularly *Sphagnum* presence (and species), cover and damage from the fire. Surface topography.
	Secondary outcome measures	Cover abundance derived from sum of classes for each 10 cm square. Mapping of distribution of classes by 10 cm squares along transects.

	Follow-up periods	Up to 15 yr post-fire.
	Methods of analysis	Summary statistics and plots by individual species.
Results		In 1977, other than the narrow unburnt strip of vegetation, no evidently living *Sphagnum* remained on the site although in many areas it was possible to find hummocks or lawns which had been severely singed by the fire rather than utterly destroyed. It was not possible to say at that time whether such damaged *Sphagnum* was alive or dead. By 1979, a few small pockets of evidently living *Sphagnum*, had appeared and much of the singed material still remained but then subsequently decomposed. This was followed by an initial flush of *S. tenellum*, a coloniser species, reaching peak cover within five yr but then declining, followed by slow re-appearance of typical bog Sphagna. This was accompanied by a similar recovery of the fire-damaged surface, changing from a relatively flat condition lacking any evident pattern to a markedly hummock-hollow topography.
Notes	Limitations identified by author	NR
	Limitations identified by review team	
	Evidence gaps and/or recommendations for further research	Similar studies of post-fire/burn effects on, and recolonisation of, a range of *Sphagnum* species on additional sites.
	Sources of funding	NCC/SNH

Evidence Table

Name of Evidence Review:	Natural England Uplands Evidence Review
Name of Review Topic:	What are the effects of managed burning on the maintenance and restoration of upland peatland biodiversity and the provision of ecosystem services?
Review Question(s)	What are the effects of managed burning on the maintenance and restoration of the characteristic floristic composition, structure and function of upland peatland habitats?

Study details	Authors	MacDonald, A.J.
	Year	2008
	Aim of study	To investigate whether past burning, or compaction from machinery or livestock passage, might have had a beneficial effect on bog regeneration, particularly *Sphagnum*
	Study design	Correlation as pt of review (correlation study assessed here)
	Quality score	2+
	External validity	EV-
Population and setting	Source population	5 lowland raised bog sites in Scotland
	Eligible population	10 potential lowland raised bog sites in Scotland with believed history of burning and/or track construction
	Inclusion and exclusion criteria	5 sites excluded from consideration due to lack of land management history, or previous forestry usage, or lack of definite burning evidence on aerial photos.

	Setting	Lowland raised bogs at Blawhorn Moss, Carnwath Moss, Flanders Moss, Red Moss of Balerno, Threepwood Moss. No information on NVC communities involved.
Methods of allocation to intervention/control	Methods of allocation	5 sites with recognisable burn extents on aerial photos & land management history
	Intervention description	Burns of different ages since 1945, both managed and wildfire. Track construction/livestock usage known or identified.
	Control/comparison description	Areas identified on individual sites as 'long unburned', 'serially burned' 'burned in wildfire 2003' etc. from sequence of aerial photos dating back to 1940s. Track impact control from paired quadrats; one within track area, one 3m outside track on alternate sides. Track samples internally buffered by 0.5m. Burning samples within internally buffered areas of 5m. All locations checked by GPS to 95% accuracy (2.4m)
	Sample sizes	8 1x1m quadrats in each type of sampled area. Randomised locations within blocks of 1/8 total potential quadrat locations for each sample area. 160 total quadrats. Also continuous transect with 158 paces in machine-cut vegetation, 158 outside, with all *Sphagnum* species recorded at each pace.
	Baseline comparisons	3 areas classified as 'long unburned'
	Study sufficiently powered	(Almost) fully randomised design for maximum statistical rigour. Adequate statistical testing applied during exploratory ordination as well as subsequent constrained ordinations and derived models. Multivariate analysis – implicit exploration of all factors & their inter-relationships Power analysis undertaken

Outcomes and methods of analysis (inc effect size, CIs for each outcome and significance)	Primary outcome measures	Treatment, bare peat, runnels, structure (T1-4, A1-4) , wetness, Clegg hammer (1 site, discarded), acrotelm assessment (1 site, discarded) % cover each *Sphagnum* species, *Erica tetralix, Empetrum nigrum nigrum,* other dwarf shrubs e.g. *Vaccinium, Molinia cearulea, Eriophorum vaginatum,* other graminoids, *Calluna vulgaris* live canopy, *Calluna* dead canopy, *Calluna* height (cm) , *Hypnum jutlandicum, Pleurozium schreberi,* other bryophytes, *Cladonia portentosa,* other non-crustose lichens, crustose lichens/algae.
	Secondary outcome measures	Derived % cover (sum of component species cover) for; dwarf shrubs, graminoids, all *Sphagnum,* non-crustose lichens.
	Follow-up periods	N/A
	Methods of analysis	R statistical package. MANOVA, ANOVA and multiple regression analysis. Cover data were arcsine square root transformed prior to undertaking analysis to ensure that the data better fitted the assumptions of normal distribution of errors, uniformity of variance etc.
Results		Highly statistically significant effects due to treatments and sites, but total *Sphagnum* cover was a less important discriminator than variables such as the total amount of dwarf shrub cover, total graminoid cover, or total cover of 'shrubby' lichens. For paired quadrats, *Sphagnum* cover difference (on-track minus off-track, or serially burned minus long unburned) between treatments was not statistically significant ($p = 0.55$) But the effect of site on differences in *Sphagnum* cover was statistically significant ($p = 0.007$). Unpaired quadrats showed a statistically significant effect of treatment ($p = 0.02$), but not site ($p = 0.70$), on *Sphagnum* cover. Highly statistically significant difference between the long unburned areas and the serially burned areas at Carnwath ($p = 0.009$).

		Statistically significant negative relationships between *Sphagnum* cover and total cover of graminoids ($p = 0.001$), non-*Sphagnum* bryophytes ($p < 0.001$), 'shrubby' lichens ($p < 0.001$), surfaces covered by algae or crustose lichens ($p < 0.001$), and a weaker positive relationship with 'wetness' ($p = 0.009$) in the minimal adequate model
Notes	Limitations identified by author	Possibility that sample areas for paired quadrats extended over wider range of substrate and hydrological conditions. 2 sites had burning/non-burning samples but no tracks. 1 site had tracks but no visible burn samples. Wetness measurements potentially affected by adverse weather conditions on some sites – may also have affected *Sphagnum* species visibility and accuracy of recording. Study sites may have been affected by serious wildfires in past (pre-'45).
	Limitations identified by review team	Slight subjectivity of 'wetness' measurement (water expressed around boots outside SW corner of quadrat). Limited study samples for track impacts and uncertainty about exact dates of track creation and burning. No indication of how other potential land management treatments e.g. grazing might interact with and affect these results
	Evidence gaps and/or recommendations for further research	Limited number of sites included in study. No examination of NVC communities involved, or potential range of impacts on different communities. Need to integrate impacts of other treatments especially grazing into the analysis.
	Sources of funding	Commissioned report by Scottish Natural Heritage, but funding not explicitly explained.

MacDonald (2008) reviewed the literature relating to the potential impact of burning and/or compaction by machinery or animals on Scottish lowland raised bogs. He also undertook a practical study of 5 lowland bogs – identifying sites with a good land management history and an aerial photographic record stretching back several decades. From the photos, areas were identified with evidence of burning and/or track construction, which were then assigned a relative date (e.g. 'serially burned', 'long unburned'), and 8 1x1m semi-randomly-located quadrats were selected, either paired with a quadrat outside the potential impact area, or unpaired, and a number of measurements of floral composition, bog structure and previous treatments were taken.

Using MANOVA and ANOVA multivariate analysis he found;

Highly statistically significant effects due to treatments and sites, but total *Sphagnum* cover was a less important discriminator than variables such as the total amount of dwarf shrub cover, total graminoid cover, or total cover of 'shrubby' lichens.

For paired quadrats, *Sphagnum* cover difference (on-track minus off-track, or serially burned minus long unburned) between treatments was not statistically significant ($p = 0.55$) But the effect of site on differences in *Sphagnum* cover was statistically significant ($p = 0.007$). Unpaired quadrats showed a statistically significant effect of treatment ($p = 0.02$), but not site ($p = 0.70$), on *Sphagnum* cover.

Highly statistically significant difference between the long unburned areas and the serially burned areas at Carnwath only ($p = 0.009$).

Statistically significant negative relationships between *Sphagnum* cover and total cover of graminoids ($p = 0.001$), non-*Sphagnum* bryophytes ($p < 0.001$), 'shrubby' lichens ($p < 0.001$), surfaces covered by algae or crustose lichens ($p < 0.001$), and a weaker positive relationship with 'wetness' ($p = 0.009$) in the minimal adequate model

The difference in wetness between on-track and off-track showed a complete lack of statistically significance ($p = 0.50$).

These results indicated that highly significant differences between sites and treatments were little related to differences in *Sphagnum* cover. There was no significant relationship between *Sphagnum* cover and dwarf shrub (mainly *Calluna*) cover, although there were significant negative relationships between *Sphagnum* cover and cover of graminoids, other bryophytes, shrubby lichens, and crustose lichens. The effects of tracks depended on the wetness of the ground, with most tracks being less wet than adjacent non-track areas.

These results are not judged to provide sufficient justification for routine burning or compaction as a restoration tool on raised bogs.

Evidence Table

Name of Evidence Review:	Natural England Uplands Evidence Review
Name of Review Topic:	What are the effects of managed burning on the maintenance and restoration of upland peatland biodiversity and the provision of ecosystem services?
Review Question(s)	What are the effects of managed burning on the maintenance and restoration of the characteristic floristic composition, structure and function of upland peatland habitat?

Study details	Authors	Marks, T.C. & Taylor, K.
	Year	1972 (and 1971 Taylor & Marks ref.)
	Aim of study	To investigate the effect of burning and sheep grazing on the mineral nutrient status of Cloudberry, *Rubus chamaemorus*.
	Study design	Randomised (partially) Control Trial
	Quality score	1+
	External validity	EV+
Population and setting	Source population	North England, North Pennines, Cumbrian uplands
	Eligible population	*Calluna-Eriophorum* blanket mire
	Inclusion and exclusion criteria	Area within defined long term experimental plots Grazing pressure – grouse plus low density of sheep
	Setting	Moor House NNR

Methods of allocation to intervention/control	Methods of allocation	*Grazing/burning effects* Pre-defined burning treatment in grazed section of 1 block of 4 replicate long-term experimental plots: 2 x Burn treatments plus no burn randomised within each block *Experimental clipping/nutrient addition* 20, $1m^2$ samples clipped to bog surface in grazed & ungrazed 20yr rotation plots; ash returned to 10, $1m^2$ clipped area allocated at random:
	Intervention description	*Grazing/burning effects* 10yr burn rotation - 2nd burn in 1965 Grazing present *Simulated burning with independence of above and below ground impacts:* Complete vegetation canopy removal with subsequent ashed biomass nutrient addition, grazing +/-
	Control/comparison description	*Grazing/burning effects* 20yr burn rotation No grazing *Experimental clipping/nutrient addition* Canopy removal with no nutrient addition, no grazing 1st versus 2nd season response
	Sample sizes	*Grazing/burning effects*

		2 burn treatments x 2 grazing treatments x 10 samples = 40 per sampling occasion 2 burning treatments x 2 grazing treatments x 1 sample for rhizome/root fraction *Experimental clipping/nutrient addition* Clipped with nutrient addition x 2 grazing treatments x 10 replicates = 20 samples on each observation occasion (1st & 2nd season)
	Baseline comparisons	*Grazing/burning effects* 20yr rotation burn with no grazing = 10 samples per occasion *Experimental clipping/nutrient addition* Clipped with no nutrient addition x 2 grazing treatments x 10 replicates = 20 samples on each observation occasion (1st & 2nd season)
	Study sufficiently powered	*Grazing/burning effects* In earlier paper (Taylor & Marks 1971) authors refer to use of initial study to define minimum sample sizes required to generate treatment differences @p=0.05 Inadequate replication for rhizome/root aspect – 1 x sample *Experimental clipping/nutrient addition* Sample size moderate with large SE of mean.
Outcomes and methods of analysis (inc effect size, CIs for each outcome and significance)	Primary outcome measures	*Experimental clipping/nutrient addition* No. of shoots/m^2 No. of fruits/m^2 *Grazing/burning effects* Total dry weight and total N, P, K, Ca & Mg for each of: leaf lamina, stems+petioles (+flowers),

		rhizomes, & roots
	Secondary outcome measures	*Grazing/burning effects* Total dry weight/m^2 and total N, P, K, Ca & Mg for each of: aerial parts, leaf laminae, stems (+petioles+flowers), rhizomes, & roots.
	Follow-up periods	*Grazing/burning effects* Identical for all plots: 5 occasions between May-August 1969 *Experimental clipping/nutrient addition* 3 & 15 months following treatment
	Methods of analysis	Standard error of means used as comparator on graphs of seasonal trend, but based on dry matter rather than nutrient concs. as the latter are scaled to m^2 using above ground biomass. No ANOVA presented No statistical analysis for single-sample values for rhizomes & roots Mean values for dry weight and mineral nutrient contents for fruits, with no sample size or SD shown.
Results		**Trends with precision as differences in standard error of mean (i.e. p=0.05)**. *Grazing & burning* Differences in total nutrient contents/m^2 reflect those in aerial biomass, by which they are scaled, i.e. without grazing plants accumulate more dry matter during the year and therefore more total nutrients; plants in plots burnt more recently also achieve a higher total dry matter/nutrient content but the magnitude is much smaller. There are no clear differences in the nutrient concentrations in for each organs type

		among the various treatments. Shoot and fruit densities are greater in fenced plots, and the addition of nutrients has no significant effect whether or not plots are grazed either in the 1st or 2nd year after clipping/nutrient addition. **Trends with no statistical precision**: For each nutrient, the total content/m^2 is greater in the fenced, 10yr burn. The concentration of N, P, K, Ca & Mg in aerial shoots and fruits from Moor House NNR are of a similar magnitude to those of samples from Norway.
Notes	Limitations identified by author	Single sample for rhizome/root aspect
	Limitations identified by review team	Sampling is in 1969, 4 yrs after the second burn of the 10yr rotation. The effects of fertilisation from ash may be more immediate than is being credited, with the historic effect manifest as enhanced current biomass & shoot density rather than current plant tissue concentrations. Sheep may be attracted into the area disproportionately in the 1-2yrs post burn so the grazing/burning effect may incorporate an indirect component . Single sample for rhizome/root data leads to low explanatory power. Experimental clipping/nutrient addition considers shoot and fruit density only, with no nutrient data. Experimental clipping and fertilising with derived ash: was at a very small scale, whereas burning will modify the above ground environment to a much greater extent; was undertaken in April which is outside the normal burn season, when plants are

		dormant; authors do not state the temperature at which the above ground biomass was incinerated and how this compared to the range expected in normal burns or those at Hard Hill.
	Evidence gaps and/or recommendations for further research	Monitoring the impact of burning in the immediate or more immediate post-burn phase, with and without grazing. A comparative approach using existing autecological data to identify the suite of upland peatland species most likely to be constrained by climate rather than nutrient availability – as a starting point for considering how burning may interact with climate change?
	Sources of funding	NERC

Taylor & Marks (1971) and Marks & Taylor (1972) used one of the four replicate blocks at the Hard Hill long term experimental burning site in Moor House NNR to study the effect of burning and grazing on the growth of Cloudberry, *Rubus chamaemorus*. Cloudberry is found strictly in *Calluna-Eriophorum* blanket mire but with a restricted geographic distribution; this is attributed to climate but the factors affecting the production of flowers and fruit not understood.

The authors counted shoot and fruit densities and harvested the aerial biomass of Cloudberry on 4 occasions between June and August 1969 in 10, 1m^2 quadrats located at random within 25mx25m in plots subject to 10yr and 20yr burn rotations, either with or without sheep grazing at a low stocking rate. The last burn for the 10yr rotation was 1965, 4 years before the study period.

Aerial biomass was harvested and segregated into leaves and stems plus petioles (plus flowers), for which total dry weight, N, P, K, Ca and Mg contents were determined. The total numbers of flowers and fruits present per plot was enumerated on each sampling occasion. The rhizome and root fraction was separated from a single core sample of 0.08m diameter by 0.5m depth in August 1969 and the same suite of parameters was quantified. The ratio of shoot:root biomass was determined per plot and used to estimate each parameter per m^2.

In an experiment to discriminate the effects following burning of canopy removal and nutrient addition 20 x $1m^2$ samples within the 20yr burn rotation plots were clipped of all biomass down to the bog surface in April 1969. Bulked biomass was incinerated and the resulting ash was applied to 10 of the clipped plots, selected at random. The density of shoots and fruits produced in each $1m^2$ was monitored 3 and 15 months following treatment.

The density of shoots and total above ground biomass was highest in the 10yr burn rotation plots and much more so in the absence of grazing: the effect was also manifest in rhizome biomass. However, individual shoot weights were similar between 10yr and 20yr burn rotations subject to grazing, where shoot density tended to drop between mid-July & August. Grazing causes a proliferation of smaller shoots with a lower propensity to flower and set fruit.

There were no differences among treatments in the concentrations in aerial dry matter of total N, P, K, Ca & Mg, so that total nutrient content per m^2 mirrored aerial biomass.

The addition of inorganic nutrients to clipped vegetation was far less influential than grazing in constraining the density of shoots and flowers: plants in fenced plots accrued an even higher density of both in the 2nd season after burning.

The authors conclude that the ability of Cloudberry to maintain internal nutrient concentrations in plots where plants are released from grazing and able to proliferate vigorously demonstrates that nutrients do not limit its growth. Furthermore, sheep appear to seek out Cloudberry. Managed burning will not therefore benefit this or other plant species whose distribution and abundance is controlled more by climate and/or synecological relationships.

Evidence Table

Name of Evidence Review:	Natural England Uplands Evidence Review
Name of Review Topic:	What are the effects of managed burning on the maintenance and restoration of upland peatland biodiversity and the provision of ecosystem services?
Review Question(s)	

Study details	Authors	Marrs, RH, Phillips, JDP, Todd, PA, Ghorbani, J & Le Duc, MG
	Year	(2004
	Aim of study	To evaluate control strategies for Molinia at two contrasting sites in different upland regions.
	Study design	1, RCT
	Quality score	1+
	External validity	EV+
Population and setting	Source population	Stands of Molinia dominated moorland – including 'white' moorland with Molinia only and 'grey' moorland where there is some Calluna remaining in the vegetation.
	Eligible population	Moorland dominated by Molinia in North Peak and Yorkshire Dales ESA.
	Inclusion and exclusion criteria	Sites with white and grey moorland selected in each area – typical of Molinia-dominated sites in Britain.
	Setting	North Peaks ESA and Yorkshire Dales ESA

Methods of allocation to intervention/control	Methods of allocation	Two areas at each site each approx 4000m2. Treatments applied in nested design – all allocated randomly.
	Intervention description	Half selected at random to be burned the other half left unburned. In each burning area three grazing treatments were applied (open all year, summer only and ungrazed control). Within each grazing area there were 3 herbicide treatments two with glyphosate application at different rates and untreated control. On white moorland additional treatment s of raking and applying Calluna seed were applied .
	Control/comparison description	Factorial design with untreated control for each treatment.
	Sample sizes	In years 1996 – 2000 4 random 1x 1 quadrats per treatment (cover of each species). Vegetation height recorded in 20 random locations per treatment. Calluna seedling emergence recorded in the subsidiary experiment in 3 0.5 x 0.5 plots in 1996 – 2000.
	Baseline comparisons	Through untreated controls.
	Study sufficiently powered	Factorial experimental design and random sampling.
Outcomes and methods of analysis (inc effect size, CIs for each outcome and significance)	Primary outcome measures	Effects of treatment on vegetation height Effects of treatment on cover of live and dead Molinia Effects on non-target species Effects of litter removal and seedling addition
	Secondary outcome measures	Effects of treatments on community response
	Follow-up periods	Experiment conducted over 6 years - 1996 -2000.

	Methods of analysis	Univariate analysis for vegetation height, species cover and Calluna seedlings . ANOVA for effects of region, moorland type, treatments and their interactions on species and vegetation height. Detrended correspondence analysis, CANOCO and ANOVA analyses of community response
Results		Herbicide application reduced vegetation height. The effect persisted throughout the experiment but by year 5 height in treated plots approached that of controls. There was no significant difference between rates of herbicide application. Burning reduced height but there was rapid recovery within two years. Cover of live Molinia was reduced only by herbicide application with the effect still significant after 6 years. Herbicide produced consistent significant responses in species cover . Effects of other treatments on species cover were variable and inconsistent between sites and between years. Responses to herbicide treatment were reduced cover of most dwarf shrubs, but increased cover of Erica tetralix, Juncus squarrosus and Polytricum commune. Grasses and sedges tended to show conflicting responses. . Effects of litter removal and application of Calluna seed produced variable results; There were short term increases in seedling density in plots where there was herbicide treatment. Large numbers of seedlings established in the year following seed application in plots where seed was applied without litter removal and where there was litter removal only. Seedling densities declined from year two onwards. There was little difference in community composition between burn treatments. Herbicide treatment at Peak ESA sites had little effect on vegetation composition but at Dales sites there appeared to be a tendency for herbicide to increase acid grassland species. Community change may be delayed several years after treatment.

Notes	Limitations identified by author	A third experimental location was abandoned due to vandalism (Exmoor). Site was a major factor separating responses to treatment – confusing effects of treatment. White vs grey moor differences not clear in the Yorkshire Dales. Responses to treatment may continue longer than the period of the experiment. Grazing treatments were insufficiently different – actual grazing rates were not measured (only grazing period).
	Limitations identified by review team	Investigation predicated on the assumption that greater dwarf shrub cover is a positive outcome. Grazing treatments relied on grazier's behaviour. Grazing by sheep only.
	Evidence gaps and/or recommendations for further research	Effect of grazing by cattle / horses. Assessment of management of Molinia dominated moorland on a wider range of outcomes. E.g. breeding birds, floristic diversity
	Sources of funding	DEFRA.

Evidence Table

Name of Evidence Review:	Natural England Uplands Evidence Review
Name of Review Topic:	What are the effects of managed burning on the maintenance and restoration of upland peatland biodiversity and the provision of ecosystem services?
Review Question(s)	d) water quality/colouration.

Study details	Authors	McDonald *et al*.
	Year	1991
	Aim of study	Summary of wide-ranging work over four years (16 reports) for Yorkshire Water mainly relating to the issue of water discolouration. This included consideration of the effect of burning.
	Study design	2: lab and field studies, including catchment-scale studies at various sites, process studies and specifically the effect of burning including small-scale experiments and a literature review.
	Quality score	2++
	External validity	EV+
Population and setting	Source population	Various moorland sites mainly in Yorkshire
	Eligible population	Yorkshire moorland, particularly YW catchments.

	Inclusion and exclusion criteria	NR
	Setting	Yorkshire moorland, particularly YW catchments.
Methods of allocation to intervention/control	Methods of allocation	NR
	Intervention description	Burning etc.
	Control/comparison description	NA
	Sample sizes	Various. Lab studies used peat cores collected from two moorland sites (Howstean and Inmoor).
	Baseline comparisons	NA
	Study sufficiently powered	NR
Outcomes and methods of analysis (inc effect size, CIs for each outcome and significance)	Primary outcome measures	Colour, Fe, Al, and Mn in leached samples from 5 cm sections of peat cores.
	Secondary outcome measures	
	Follow-up periods	
	Methods of analysis	
Results		Leachate data were provided from peat cores. They showed that one month after burning there was no difference in colour leaching from burnt and unburnt peat cores. However, over longer periods prescribed burning increased colour in leachate

		compared to unburnt peat cores vegetated with *Calluna* and *Eriophorum*. Some of the peat cores were burnt in the field by normal planned controlled fires and then extracted and returned to the laboratory whereas other peat cores has their vegetation burnt at controlled hot and cooler temperatures in the laboratory and were then leached with water. Hotter burns were associated with more colour release than cooler burns. This was the case for both the controlled laboratory burns and for field samples. However, in the field 'hot burns' were assumed from the state of the peat surface and vegetation rather than by temperature measurement or control. The lag between burning and colour increase was used as evidence to suggest that burning did not directly cause colour increases but lead to other changes which then in turn lead to colour increases. It was suggested that these processes might include accelerated microbial decomposition in warmer temperatures below an unvegetated peat surface compared to under a cooler vegetated surface (see also below re. related catchment-scale studies.)
Notes	Limitations identified by author	
	Limitations identified by review team	Limited sample size and distribution of sites.
	Evidence gaps and/or recommendations for further research	
	Sources of funding	Yorkshire Water.

Evidence Table

Name of Evidence Review:	Natural England Uplands Evidence Review
Name of Review Topic:	What are the effects of managed burning on the maintenance and restoration of upland peatland biodiversity and the provision of ecosystem services?
Review Question(s)	What are the effects of managed burning on the maintenance and enhancement of the characteristic fauna of upland peatland habitats either directly or indirectly through changes in vegetation composition and structure?

Study details	Authors	McFerran, D.M., McAdam, J.H. & Montgomery, W.I. [invert. Aspects]
	Year	1995
	Aim of study	To describe changes in the assemblages of ground beetles and spiders in response to heathland burning. [See separate ET re vegetation change.]
	Study design	Correlation
	Quality score	2-
	External validity	EV+ has some general application to peatland burning
Population and setting	Source population	Northern Ireland
	Eligible population	Upland heathland
	Inclusion and exclusion criteria	Shooting rights under single ownership therefore managed burning practiced 90% of area known to be over deep peat.

	Setting	Common land, Ballycastle, County Antrim
Methods of allocation to intervention/control	Methods of allocation	No details. No definition of different burn areas or information source
	Intervention description	Burnt 1982 – extensive wildfire covering 30ha Burnt 1988 – (multiple) managed burns ca. 30mx60m Grazing by sheep
	Control/comparison description	'No burn' – time frame not defined No grazing
	Sample sizes	3 burn treatments x 2 grazing treatments x 3 replicate plots (cumulative data spanning 18 month period 1989-1990) = 18 observations
	Baseline comparisons	Unburnt area with no grazing
	Study sufficiently powered	Sample size rather small for multivariate analysis Adequate for factorial ANOVA (no detail provided)
Outcomes and methods of analysis (inc effect size, CIs for each outcome and significance)	Primary outcome measures	Total no.s of individual species of each of spiders and ground beetles for the entire 18 month sampling period
	Secondary outcome measures	Presence/absence based assemblages for each of spiders and ground beetles
	Follow-up periods	18 months (sampled 1989 & 1990)

	Methods of analysis	ANOVA of $\log_e$transformed abundance data for individual species & total numbers of each taxa trapped – Inappropriate for species with large numbers of zero values. Using presence/absence assemblages for each taxon: DECORANA with Spearman rank correlation applied to individual axis scores for species and key botanical variables (no details provided) TWINSPAN classification
Results		2 species of ground beetle accounted for 55% of the catch Summary table presents result for individual species, with merged & shaded cells showing no significant difference. Only most abundant species have been selected as large nos. of missing values reduce legitimacy of using ANOVA.

Species	1988	1982	unburnt	p-value
GROUND BEETLES				
Total numbers	lowest			*
			lowest	**
Nebria salina	highest			***
Carabus nitens	highest			*
C. glabratus			highest	***
Pterostichus niger	lowest			***
Leistus rufescens	lowest			**
SPIDERS				
Total numbers		highest		**
Bathyphantes gracilis		highest		***
Ceratinella brevipes		highest		***
Dicymbium nigrum		highest		**
Centromerita bicolor		highest		**
Centromerita concinna		highest		**
Bolyphantes luteolus	lowest			**

Lepthyphantes alacris	lowest			**
L. zimmermanni	lowest			*

Species	Grazed	Ungrazed	p
Saaristoa abnormis		highest	*
Centromerita concinna		highest	**

Results of ordination and classification showed:

for ground beetles - some separation on Axis 2 (weak separation of 1988 burn sites) and separation of 1988 burns at 1st classification division, based on presence of *Carabis nitens*

for spiders - some separation on Axis 1 for spiders, with distinction between 1982 and other sites at the 1st division on the basis of the absence of 3 species.

no relationships with botanical variables derived from point quadrat data

Notes	Limitations identified by author	Unburnt stands are representative of the pre-burnt status of the areas burnt in 1988, but not 1982.
	Limitations identified by review team	Lack of detail for methodology places severe constraints on the value of the data and whether or not the design can detected what it purports to. The underlying assumptions of the space for time approach are likely to be invalid because the burn characteristics of wildfires are very different to those of managed burns; the time of year when the 1982 burn occurred is not stated. This may be less important for invertebrates because of their mobility. The 1982 & 1988 burns cover very different sized areas (30ha versus several 30mx60m areas) and no comment is made as to whether their physical characteristics are comparable, or the homogeneity of the 1982 burn.

		The spatial relationships of the burn areas, and particularly the small managed burns are not discussed, nor are the potential impacts of supplementary feeding of sheep, vehicular access, proximity to reseeded areas and grazer behaviour. These issues are particularly relevant to mobile species. Methodological problems also exist: No comment is made regarding edge effects in grazing exclosures and relative locations of pitfall traps. Constraining multivariate analysis to presence/absence data weakens its explanatory power, especially when comparing samples of mobile animals from very different sized burnt areas. Chance encounters of mobile species are more likely in small burn patches set among a wider matrix of unburnt ground (especially given plots were 30mx15m in areas of ca. 30mx60m), compared to the much larger 30ha expanse of the 1982 burn. Questions exist over the appropriateness of such large numbers of ANOVA tests and their use for data sets with multiple missing values.
	Evidence gaps and/or recommendations for further research	Study needs designing to address basic requirements of methodological and statistical robustness for ecological field studies – or at least provide sufficient information to enable an informed judgement of this.
	Sources of funding	Department of Agriculture for Northern Ireland.

McFerran at al. (1995) studied the ground beetle and spider assemblages of *Calluna*-dominated heathland in response to burning and grazing, in managed moorland at Ballycastle in the north of County Antrim, Northern Ireland, to identify patterns of invasion and possible successional sequences. The site is common grazing (entirely hill sheep, present for the 75% of the year) but shooting rights, exercised historically for red grouse, are single-ownership. Three areas of moorland were defined, deemed to represent ‘space for time’: unburnt vegetation; vegetation burnt in 1982 when an extensive wildfire affected 30ha; and areas of ca. 30mx60m subject to managed burning in autumn 1988.

Three replicate monitoring plots of 30mx15m were established in each of the burn types; the effect of vertebrate grazing was also investigated by erecting three replicate grazing exclosures in each. Three replicate pitfall traps were installed in each plot and the preserved contents collected at 4-6 week intervals over an 18 month period in 1989-1990 with data combined to produce a single observation. Abundance data were $\log_e$ transformed and subject to ANOVA. Assemblages derived from presence/absence data for each taxon were analysed by multivariate ordination and classification. The relationship between ordination axis scores and botanical variables derived from point quadrat data were explored by rank correlation.

The results suggest that burning has more effect on the assemblage of invertebrates than a short period without grazing and that the patterns of invasion over time are different for ground beetles and spiders. The most distinctive assemblage of ground beetles was found in the 1988 burn, which had the highest catches of *Carabis nitens* and *Nebria salina* ($p<0.05$ & 0.001, respectively) but the lowest of *Pterostichus niger* and *Leistus rufescens* ($p<0.001$ & 0.01, respectively). Most *Carabis glabratulus* were recorded from unburnt areas ($p<0.001$). In contrast, the greatest numbers of spiders were trapped in the 1982 burn ($P<0.01$), where 5 species were at their most abundant (p-values of 0.01 or 0.001): three species were least prevalent among newly burnt vegetation ($p<0.01$ and <0.05 for 1 species).

Successional trends and the impact of grazing were discriminated poorly by both ordination and classification although 1988 plots showed some separation on axis 2 for ground beetles while the presence of *Carabis nitens* distinguished these samples at the first division of the classification. No relationships between axis scores and key botanical variables were elucidated. Nevertheless, the authors argue that there is evidence that distinct assemblages and/or individual species can be related to the changing composition and structure of *Calluna*-dominated heath. The list of ground beetle species recorded at Ballycastle were compared to a previously published classification derived for 42 peat sites in Northern England and corresponded most closely to type 1, typical of dry heath-like moorland of an appropriate altitudinal range and peat depth.

Evidence Table

Name of Evidence Review:	Natural England Uplands Evidence Review
Name of Review Topic:	What are the effects of managed burning on the maintenance and restoration of upland peatland biodiversity and the provision of ecosystem services?
Review Question(s)	What are the effects of managed burning on the maintenance and restoration of the characteristic floristic composition, structure and function of upland peatland habitat?

Study details	Authors	McFerran, D.M., McAdam, J.H. & Montgomery, W.I. [Vegetation aspects]
	Year	1995
	Aim of study	To describe changes in the heathland plant community in response to burning. [See separate ET for invertebrate monitoring.]
	Study design	Correlation
	Quality score	2-
	External validity	EV-
Population and setting	Source population	Northern Ireland
	Eligible population	Upland heathland
	Inclusion and exclusion criteria	Shooting rights under single ownership therefore managed burning practiced 90% of area known to be over deep peat.
	Setting	Common land, Ballycastle, County Antrim

Methods of allocation to intervention/control	Methods of allocation	No details. No definition of different burn areas or information source
	Intervention description	Burnt 1982 – extensive wildfire covering 30ha Burnt 1988 – (multiple) managed burns ca. 30mx60m Grazing by sheep
	Control/comparison description	'No burn' – time frame not defined No grazing
	Sample sizes	**3 burn treatments x 2 grazing treatments x 3 replicate plots (**1989 & 1990): % frequency = 100 hits/plot (10 x 10-pin frames?) = 18 observations for each year **2 burn treatment x 2 grazing treatments x 3 replicate plots** **(**1989 & 1990) Canopy height = 25 measurements/plot = 300 for each year % biomass contribution = 3 sample/plot = 36 for each year Total no. of hits for 7 height strata (Inclined point quadrat) = 12 observations for each year % composition for 7 height strata = 12 for each year **% frequency in 1988 burn only 18 x monthly records from 1989-1990** = 18 repeat measures x 2 grazing treatments for each month
	Baseline comparisons	Unburnt area with no grazing
	Study sufficiently	% cover data adequate & statistically appropriate

	powered	Canopy height adequate Biomass data only sampled from 0.017% of plot area – not adequate Inclined point quadrat data adequate for both measures (but issues over large no.s of ANOVAs?) % frequency over 18 months 1989-1990 repeated measures for very small sample area, deemed inadequate
Outcomes and methods of analysis (inc effect size, CIs for each outcome and significance)	Primary outcome measures	% cover of species Canopy height of vegetation (cm) Dry biomass of species Total hits per species for each of 7, 5cm interval height strata % frequency of species
	Secondary outcome measures	% biomass contribution % species composition for each of 7, 5cm height strata No.s of species in different life-form categories
	Follow-up periods	12 months (sampled 1989 & 1990) BUT 18 months for frequency data from 1988 burn only
	Methods of analysis	ANOVA Structure not discussed - ambiguous Appears to be factorial for some comparisons where interactions are identified, otherwise no comments regarding interaction

Results		Only results of interest reported – large nos. of comparisons have been analysed; many yield only intuitive trends (e.g. the location of the live *Calluna* canopy changes with time, i.e. as bushes grow) and others are questionable because of the rigor of the analysis. Basic expected effects of grazing identified after 12 month period (canopy height reduced, live *Calluna* & total biomass reduced, $p<0.05$) Higher % of live *Calluna* in 1982 compared to unburnt ($p<0.001$) i.e. 1982=building phase *Vaccinium myrtillus* benefits from burning in the short term ($p<0.05$) and trends suggest it responds rapidly to release from grazing (no precision). Life-form type did not explain interspecific variations in % frequency in the 18 month period following burning.
Notes	Limitations identified by author	Unburnt stands are representative of the pre-burnt status of the areas burnt in 1988, but not 1982.
	Limitations identified by review team	Lack of detail for methodology places severe constraints on the value of the data, not only in terms of whether or not the design can detected what it purports to, but also the subsequent statistical treatment. The underlying assumptions of the space for time approach are likely to be invalid because the burn characteristics of wildfires are very different to those of managed burns; the time of year when the 1982 burn occurred is not stated. The 1982 & 1988 burns cover very different sized areas (30ha versus several 30mx60m areas) and no comment is made as to whether their physical characteristics are comparable and the homogeneity of the 1982 burn across the 30ha. Small burn patches are set among a wider matrix of unburnt ground (especially given plots were 30mx15m in areas of ca. 30mx60m), compared to the much larger 30ha

		expanse of the 1982 burn. The spatial relationships of the burn areas, and particularly the small managed burns are not discussed, nor are the potential impacts of supplementary feeding of sheep, vehicular access, proximity to reseeded areas and grazer behaviour. Methodological problems also exist: No comment is made regarding edge effects in grazing exclosures. Exclosures claim to exclude 'all vertebrate herbivores', but this is not justified (vole-proof?!) Does not address the context of this site relates to similar vegetation types (i.e. it is very close to the coast) Very small numbers of permanent quadrats are used, which sample extremely small proportions of the available area, and repeated measures are taken. Similar issues relate to the above ground biomass data, which sample a total of <0.2% of the area on each occasion
	Evidence gaps and/or recommendations for further research	Study needs designing to address basic requirements of methodological and statistical robustness for ecological field studies – or at least provide sufficient information to enable an informed judgement of this.
	Sources of funding	Department of Agriculture for Northern Ireland.

McFerran at al. (1995) studied the composition and structure of *Calluna*-dominated heathland in response to burning and grazing, in managed moorland at Ballycastle, in the north of County Antrim, Northern Ireland, to compare post-fire succession with published studies for *Calluna* elsewhere. The site is common grazing (entirely hill sheep present for the 75% of the year) but shooting rights, exercised historically for red grouse, are single-ownership. Three areas of moorland were defined, deemed to represent 'space for time': unburnt vegetation; vegetation burnt in 1982 when an extensive wildfire affected 30ha; and areas of ca. 30mx60m subject to managed burning in autumn 1988.

Three replicate monitoring plots of 30mx15m were established in each of the burn types; the effect of vertebrate grazing was also investigated by erecting three replicate grazing exclosures in each. The % cover of species and the actual and relative canopy contribution in 7 contiguous 5cm height strata was determined by point quadrat in autumn 1989 & 1990. Vegetation canopy height and proportional contribution of species to above ground biomass was assessed for unburnt and 1982 burns only, in autumn 1989 & 1990. The % frequency of species in the newly burnt stands was monitored monthly in permanent quadrats for a period of 18 months.

The results indicate that areas burnt in 1982 have a higher proportion of live to dead Calluna biomass than the unburnt stands ($p<0.001$), where more litter has accumulated ($0.5>p<0.001$) and the canopy height is greater ($p<0.001$). An increase in above ground biomass, canopy height and contribution of live *Calluna* expected on release from grazing was detected after a period of 12 months ($p<0.05$ for each). These trends are also reflected in differences in % cover among the 3 burn types. The % cover of *Vaccinium myrtillus* was highest in the most recently burnt areas ($p<0.05$ for each pair-wise comparison). *Carex* species were most prevalent in the 1982 burn plots. Live *Calluna* biomass was distributed higher within the vegetation canopy in unburnt compared to both burnt areas ($p<0.01$).

Burning is shown to initiate complex successional pathways which have characteristics species associations.

Evidence Table

Name of Evidence Review:	Natural England Uplands Evidence Review
Name of Review Topic:	What are the effects of managed burning on the maintenance and restoration of upland peatland biodiversity and the provision of ecosystem services?
Review Question(s)	What are the effects of managed burning on the maintenance and enhancement of the characteristic fauna of upland peatlands either directly or indirectly through changes in vegetation composition and structure?

Study details	Authors	Miles, J
	Year	1971
	Aim of study	To remove litter from Molinia dominated vegetation by burning and then determine whether these areas were more heavily grazed than unburned areas and how long any effect persisted.
	Study design	Experiment – comparison of burned and unburned areas.
	Quality score	1+
	External validity	EV+
Population and setting	Source population	Molinia-dominated vegetation on Rhum.
	Eligible population	Strips of vegetation burned in spring 1967 and adjacent unburned ground.
	Inclusion and exclusion criteria	Site chosen as a mosaic of Molinia dominated grassland with Trichophorum-Eriophorum blanket bog with abundant Molinia.

	Setting	Upland moorland with vegetation referable to NVC M17 and M25.
Methods of allocation to intervention/control	Methods of allocation	No explanation for location of experimental burn strips or transects across the boundary between burned/unburned along which vegetation was sampled. Molinia litter sampled in random quadrats but other sampling allocation not explained.
	Intervention description	Burning of 2 x 2ha strips of vegetation and temporary exclusion of deer grazing from 4x4 m plots.
	Control/comparison description	Unburned areas adjacent to burned plots.
	Sample sizes	2 experimental burned areas. 4 8x30m transects across each strip with 20 quadrats in each to assess grazing of Molinia on 10 days in 1967 and one day each in 1968 and 1969. Faecal material collected in three periods in 1967. Deer numbers counted on 10 days in 1967 and one day each in 1968 and 1969. Molinia litter collected in 4 quadrats per transect (n=16) in 1967 and 1969. 2 quadrats to assess cover and abundance of plant species in plots protected from grazing.
	Baseline comparisons	Not reported.
	Study sufficiently powered	Rationale for and method of analysis not fully explained.
Outcomes and methods of analysis (inc effect size, CIs for each outcome and	Primary outcome measures	Mean numbers of deer on burned and unburned ground. Rates of deposition of faecal pellets on burned vs unburned ground. Estimates of the frequency of grazing of Molinia in burned vs unburned ground. Estimation of dry matter of Molinia consumed by fire in 1967 and accumulated in

significance)		1967/8.
	Secondary outcome measures	None.
	Follow-up periods	Year of treatment and two following years (1967 then 1968/9).
	Methods of analysis	Correlation of rates of faecal matter deposition and frequency of grazing. Chi-square comparison of frequency of grazing between burned/unburned areas. Simple comparison (means and SD?) of rates faecal matter deposition and % fresh grazed Molinia in burned vs unburned and between litter dry weights in grassland vs bog vegetation.
Results		Burning Molinia-rich vegetation increased attractiveness of the sward to deer with most grazing deer in the area seen in the grazed plots in the 10 weeks following burning. Analysis of faecal pellet deposition and rates of shoot grazing confirmed that grazing rates in burned plots were greater than in unburned areas. In the years following burning grazing rates on the burned plots and in unburned areas were similar. Burning reduced litter by 80% on grassland and 85% on bog but within two years the quantity of litter had increased to half that on unburned areas. Burning did not cause change in vascular plant abundance but killed most of the Sphagnum moss cover. This had largely recovered within two years.
Notes	Limitations identified by author	None.
	Limitations identified by review team	Study concentrates on grazing value so of limited scope – other objectives such as biodiversity, ecosystem services etc are not considered.
	Evidence gaps and/or recommendations for	See limitations.

	further research	
	Sources of funding	Nature Conservancy.

Evidence Table

Name of Evidence Review:	Natural England Uplands Evidence Review
Name of Review Topic:	What are the effects of managed burning on the maintenance and restoration of upland peatland biodiversity and the provision of ecosystem services?
Review Question(s)	d) water quality/colouration.

Study details	Authors	MITCHELL & MCDONALD [Also aspects of McDonald *et al*. 1991.]
	Year	1995
	Aim of study	A study of factors involved in increases in water colouration based on their field observations in northern England, particularly in the Nidd and Washburn catchments in Yorkshire.
	Study design	2: catchment modelling
	Quality score	2-
	External validity	EV-
Population and setting	Source population	R Burn catchment in North Yorkshire.
	Eligible population	R Burn catchment.
	Inclusion and exclusion criteria	
	Setting	R Burn catchment.

Methods of allocation to intervention/control	Methods of allocation	
	Intervention description	Managed burning etc.
	Control/comparison description	NA
	Sample sizes	45 streams in one catchment each with 14 grab samples over one year.
	Baseline comparisons	NA
	Study sufficiently powered	NA
Outcomes and methods of analysis (inc effect size, CIs for each outcome and significance)	Primary outcome measures	Water colouration (absorbance at 400 nm).
	Secondary outcome measures	
	Follow-up periods	NA, though sampled over one year.
	Methods of analysis	Summary statistics but not statistical analysis.
Results		McDonald *et al*. (1991) suggested that key factors contributing to increased colour risk in upland peatlands were: drought conditions, area of open-cut drainage, area of pre-afforestation ditching, areas of severely burnt moorland, south facing slopes, and areas of bare eroded peat. In their original report, McDonald et al. (1991) state that the links between burning and colour were not clear cut, mainly because the data on burnt area, types of burn and other confounding factors (e.g. drainage and burning occurring together etc) were rather limited. Later, Mitchell and McDonald (1995) suggested there was a link between colour and burning (and drainage) but it was acknowledged that there was insufficient data for a statistical validation of this link.

Notes	Limitations identified by author	Lack of statistical validation.
	Limitations identified by review team	Single study catchment.
	Evidence gaps and/or recommendations for further research	
	Sources of funding	Yorkshire Water?

Evidence Table

Name of Evidence Review:	Natural England Uplands Evidence Review
Name of Review Topic:	What are the effects of managed burning on the maintenance and restoration of upland peatland biodiversity and the provision of ecosystem services?
Review Question(s)	b) effects on fauna.

Study details	Authors	Moss *et al*. Also related refs: Crick *et al.* (2006) and Newson *et al*. (2007).
	Year	2005
	Aim of study	To access timing of egg-laying and other breeding activity of upland, principally moorland, bird species
	Study design	2: analysis of data from two principle long-term, ongoing national survey datasets, plus several other smaller more local datasets.
	Quality score	2++
	External validity	EV++
Population and setting	Source population	Moorland bird species and records of species nesting in upland areas (CS2000 environmental zone).
	Eligible population	As source population.
	Inclusion and exclusion criteria	NA

	Setting	GB moorland/uplands (peatland not differentiated).
Methods of allocation to intervention/control	Methods of allocation	NA
	Intervention description	NA. But date of egg-laying considered in relation to legal burning season (ending 15 April).
	Control/comparison description	NA
	Sample sizes	Ongoing sample from national Nest Record Scheme and ringing nestlings: NRS, 4,284 Nest Record Card (NRC) records; and ringing of nestlings (26,043 records); and two smaller data sets: the GWCT's long-term data set on Scottish red grouse (318 nests); and the RSPB's hen harrier nest data (1,235 nests although only 17 were from England).
	Baseline comparisons	NA
	Study sufficiently powered	Not reported, though sample sizes, especially from NRS, large.
Outcomes and methods of analysis (inc effect size, CIs for each outcome and significance)	Primary outcome measures	Date of first egg laying and relationship with location, altitude, latitude, time (yr) etc.
	Secondary outcome measures	Breeding success and change over time through the season. Dates of site occupation and breeding activity.
	Follow-up periods	NA
	Methods of analysis	Regression analysis of dates, breeding success in relation to various factors inv=cluding time and aspects of location.

Results		Of the priority species, only nine (39%) had 10% or more (all but one 20% or more) of first eggs laid in nest attempts in England by 15 April (the end of the legal burning season). Among these were some potentially vulnerable ground/vegetation-nesting species: lapwing, golden plover, redshank, snipe, short-eared owl and stonechat. A further two species had more than 5% of first nest attempts by 15 April in England based on NRS data: hen harrier and skylark. Of the subsidiary species, five out of 12 had 5% or more of first eggs laid by 15 April, though none were ground/vegetation-nesters. Additional GWCT Scottish red grouse data confirm the relatively late breeding of this species with few first eggs predicted to be laid by 15 April, though there was variation between years and some evidence of later laying with advancement of a week between 1992 and 2003. Laying dates were generally later in Scotland than in England and Wales. Analysis of trends in breeding performance showed that the commonest pattern was for declines in clutch (6 of 13 species) and brood size (4 out of 9 species) through the breeding season but no significant trends in other variables. Trends in overall productivity per nest attempt could only be a few species: wheatear and whinchat showed a decline and twite an increase followed by a decline. It was suggested that losses of nest during April “could have substantial impacts on the productivity” of some species at risk from burning including: wheatear and less so for hen harrier and stonechat, even if the birds could relay. A number of species are nesting earlier than at the start of the data collection (1939 for NRS) perhaps “reflecting generally earlier breeding seasons attributed in other studies to global warming”, although a smaller number of species were also laying later. Five species showed earlier laying based on NRCs and seven based on ringed nestlings. Amongst those potentially at risk from burning, these included hen harrier and lapwing becoming earlier by more than one day per year (from NRC data) and ring ouzel and twite *Carduelisflavirostris* by more than 0.3 days per year (from ringing nestlings). A literature review on pre-nesting periods, including that dates that migrant or partially migrant species return to moorland breeding grounds, as an indication of when they would potentially

		be liable to disturbance from burning operations suggested that resident species, including red and black grouse, and several waders including golden plover, lapwing and curlew, might be affected by burning particularly in March.
Notes	Limitations identified by author	The authors noted that whilst "these results can be used to indicate the vulnerability of moorland birds to burning, they do not show what proportion of nests is actually affected. This true vulnerability may depend on aspects such as the choice of nest sites in relation to types of heather that are burnt, which may in turn vary depending on the objectives of burning. For example, golden plover tend not to nest in stands of mature heather that are ready for burning as part of grouse moor management (though they nest in shorter and fragmented heaths, e.g. Ratcliffe 1976), but may be affected if a fire spreads into other more suitable habitats. They may also be affected by 'swaling' ... on grass moorland. A number of additional factors must be taken into account to assess that risk: the proportion of suitable habitat subject to management through burning; the frequency with which a managed moor is burned; and the effect of burning operations on the species' nesting attempt."
	Limitations identified by review team	Data does not differential records from peatland, though, especially some species, are liable to have peatland and other habitats within their ranges. Timing is perhaps less likely to be affected by habitat type than species' habitat associations, with certain spp. particularly associated with blanket bog, e.g. golden plover, dunlin etc.
	Evidence gaps and/or recommendations for further research	The authors suggested potential approaches to creating a vulnerability index, but noted a relative lack of data on some key aspects and did not develop it further. It was suggested that NRC data could be investigated further to determine any relationship between burning and nest failure.
	Sources of funding	SNH & Defra

Moss *et al*. (2005)/Crick *et al.* (2006)/Newson *et al*. (2007) [2++] studied the timing of breeding of birds on *moorland* in England, Scotland and Wales based on data on species which are more-or-less restricted to the uplands and data from other species' records from within the three Countryside Survey 2000 upland Environmental Zones (Haines-Young *et al*. 2000). They used two large national datasets: the Nest Record Scheme (NRS, 4,284 Nest Record Card (NRC) records) and ringing of nestlings (26,043 records); and two smaller data sets: the GWCT's long-term data set on Scottish red grouse (318 nests); and the RSPB's hen harrier nest data (1,235 nests although only 17 were from England). These data include but do not differentiate nesting on upland peatlands from other moorland habitats. Newson *et al*. (2007) updated the findings in relation to Wales.

The study presents the dates of laying of the first egg in a sample of nests for 23 'priority' moorland species and in summary form for a further 12 'subsidiary upland species'. There was generally good agreement between data from the NRS and ringing. Of the priority species, only nine (39%) had 10% or more (all but one 20% or more) of first eggs laid in nest attempts in England by 15 April (the end of the legal burning season). Among these were some potentially vulnerable ground/vegetation-nesting species: lapwing, golden plover, redshank, snipe, short-eared owl and stonechat *Saxicola rubetra*. A further two species had more than 5% of first nest attempts by 15 April in England based on NRS data: hen harrier and skylark. Of the subsidiary species, five out of 12 had 5% or more of first eggs laid by 15 April, though none were ground/vegetation-nesters. Additional GWCT Scottish red grouse data confirm the relatively late breeding of this species with few first eggs predicted to be laid by 15 April, though there was variation between years and some evidence of later laying with advancement of a week between 1992 and 2003. Laying dates were generally later in Scotland than in England and Wales. Analysis of trends in breeding performance showed that the commonest pattern was for declines in clutch (6 of 13 species) and brood size (4 out of 9 species) through the breeding season but no significant trends in other variables. Trends in overall productivity per nest attempt could only be a few species: wheatear and whinchat showed a decline and twite an increase followed by a decline. It was suggested that losses of nest during April "could have substantial impacts on the productivity" of some species at risk from burning including: wheatear and less so for hen harrier and stonechat, even if the birds could relay.

Regression analysis showed that a number of species nesting earlier than at the start of the data collection (1939 for NRS) perhaps "reflecting generally earlier breeding seasons attributed in other studies to global warming", although a smaller number of species were also laying later. Five species showed earlier laying based on NRCs and seven based on ringed nestlings. Amongst those potentially at risk from burning, these included hen harrier and lapwing becoming earlier by more than one day per year (from NRC data) and ring ouzel and twite *Carduelisflavirostris* by more than 0.3 days per year (from ringing nestlings). A literature review was also carried out on pre-nesting periods, including that dates that migrant or partially migrant species return to moorland breeding grounds, as an indication of when they would potentially be liable to disturbance from burning operations. Resident species, including red and black grouse, and several waders including golden plover, lapwing and curlew, might be affected particularly in March.

The authors noted that whilst "these results can be used to indicate the vulnerability of moorland birds to burning, they do not show what proportion of nests is actually affected. This true vulnerability may depend on aspects such as the choice of nest sites in relation to types of heather that are burnt, which may in turn vary depending on the objectives of burning. For example, golden plover tend not to nest in stands of mature heather that are ready for burning as part of grouse moor management (though they nest in shorter and fragmented heaths, e.g. Ratcliffe 1976), but may be affected if a fire spreads into other more suitable habitats. They may also be affected by 'swaling' ... on grass moorland. A number of additional factors must be taken into account to assess that risk: the proportion of suitable habitat subject to management through burning; the frequency with which a managed moor is burned; and the effect of burning operations on the species' nesting attempt." They went on to suggest potential approaches to creating a vulnerability index, but noted a relative lack of data on some key aspects and did not develop it further. However, they concluded that moving the legal burning cut-off date back to 31 March "would remove many species from significant risk." Following reviews of the Burning Regulations and Code, this subsequently happened in Wales (WAG 2008) but not in England (Defra 2007).

Evidence Table

Name of Evidence Review:	Natural England Uplands Evidence Review
Name of Review Topic:	What are the effects of managed burning on the maintenance and restoration of upland peatland biodiversity and the provision of ecosystem services?
Review Question(s)	d) What are the effects of managed burning of upland peatlands on water quality (including colouration, release of metals and other pollutants and aquatic biodiversity) and water flow (including downstream flood risk), either directly or indirectly through changes in vegetation composition and structure?

Study details	Authors	O'Brien *et al*
	Year	2005
	Aim of study	to determine if there is a spatial relationship between prescribed burning and water discolouration within the Derwent catchment in the south Pennines
	Study design	Correlation
	Quality score	2-
	External validity	EV+
Population and setting	Source population	Area of Derwent catchment in south Pennines Peak District.
	Eligible population	Catchment of Bamford Treatment Works.
	Inclusion and exclusion criteria	Study area needed generally high levels of water colour, relatively similar geology, topography and rainfall. Some parts of catchment should have regular burning regime, whilst others would be not burnt recently or not at all, to act as control.

	Setting	Upper Derwent, Westend, Mill Brook and Linch Clough catchments (Howden reservoir). These areas are different and to the NE of the sites studied in O'Brien 2009 (PhD thesis).
Methods of allocation to intervention/control	Methods of allocation	All selected sites had been part of Severn Trent water colour monitoring programme area 2001-4 which provided baseline data and showed relatively high levels of water colour.
	Intervention description	Areas of burning within catchments digitised from aerial photos for periods 1988-9, 89-91, 92-95, 96-98, 99-2003, 03-05 and estimated as percentage of total catchment area. No direct intervention.
	Control/comparison description	Varying levels of burning identified for particular areas within study catchment over time, corresponding to particular sample points.
	Sample sizes	Derwent catchment – 24 sample points. Westend 45 points. Mill Brook 19 points. Not all sample points used on each of 4 sampling dates. July 2005-Jan 2006.
	Baseline comparisons	Severn Trent Water colour data for 2001-4 gives limited comparison.
	Study sufficiently powered	No Power analysis provided. Study used more sampling points than Severn Trent monitoring 2001-4 (which showed no significant correlation) presumably to increase power.
Outcomes and methods of analysis (inc effect size, CIs for each outcome and significance)	Primary outcome measures	Water colour, PH, conductivity measured from samples. Areas of burning (as % of total catchment area) from digitised aerial photos. Height above sea level of sampling points.
	Secondary outcome measures	Geology of sampling points (Blanket bog peat, acid loamy upland soils with wet peat surface, free-draining slightly acid loamy soils).

		Rainfall data for catchment areas.
	Follow-up periods	No follow up.
	Methods of analysis	Correlation analysis (Pearson's product moment), scatterplots. Mann-Whitney U test.
Results		No significant relationship between mean true water colour (2005-6) and percentage of area burnt in either 1999-2003 (r = 0.344 p=0.210), or 1999 -2005 (r=0.441 p=0.1), though weak positive relationship. Mill Brook catchment had high percentage of burning, but produced low mean water colour results – other factors responsible. Significant negative relationship between mean true water colour and PH (r=-0.774 p=0.000) Weak linear relationship between mean true water colour and conductivity but not statistically significant (r=-0.083 p=0.489) Significant relationship between mean water colour and altitude (r=0.641 p=0.000) Mann-Whitney U Test – difference of water colour based on soil type (Winter Hill peat or Acid Loam) shows population medians not equal and difference highly significant (p=0.000) . True water colour average 133oH higher on Winter Hill Peat than on Acid Loam.
Notes	Limitations identified by author	Low baseflow conditions resulted in lower mean water colour values recorded than previous average values 2001-4. This may have reduced spacial variation of results.
	Limitations identified by review team	Not all sample points used on each of 4 sampling days. Accuracy of % cover of burning estimates may be suspect given difficulty of identifying exact areas from photographs. No real control of areas with no burning in sample period 1999 – 2005, as almost all parts of catchment had had some burning within the period. No real explanation of why 1999-2005 was used for this measurement rather

		than earlier measures dating back to 1988. No proper multivariate analysis to find relative importance of factors in relation to water colour.
	Evidence gaps and/or recommendations for further research	Further temporal and spacial sampling focussing on areas of high altitude deep peat, with variations in burning regime to try to identify relationship between burning and water colour.
	Sources of funding	Moors for the Future

Evidence Table

Name of Evidence Review:	Natural England Uplands Evidence Review
Name of Review Topic:	What are the effects of managed burning on the maintenance and restoration of upland peatland biodiversity and the provision of ecosystem services?
Review Question(s)	What are the effects of managed burning on the maintenance and restoration of the characteristic floristic composition, structure and function of upland peatland habitats?

Study details	Authors	O'Reilly, C
	Year	2008
	Aim of study	To assess the potential of Sphagna as a simple indicator of habitat condition with reference to the efficacy of upland management
	Study design	Correlation
	Quality score	2+
	External validity	EV+
Population and setting	Source population	Upland peatland, North Pennines
	Eligible population	Pre-defined peatland within the boundary of the North Pennines Natural Area
	Inclusion and exclusion criteria	Mire expanse within 20 x 1km^2 sampling sites selected at random
	Setting	North Pennines Natural Area

Methods of allocation to intervention/control	Methods of allocation	For each of 20 x 1km^2 quadrats were located at random along a transect within mire
	Intervention description	No intervention. Community description and quantification of environmental parameters
	Control/comparison description	No control/comparison. All data combined for exploratory multivariate analysis.
	Sample sizes	200 quadrats for site-specific study Additional 41 quadrats from a separate project 18+ environmental variables (all but one are quantitative, one is derived)
	Baseline comparisons	None
	Study sufficiently powered	No power calculation per se. A large number of environmental variables were considered and in this respect the study is superior to many. For the size of the area being covered 200 initial samples of 0.25m^2 is small and even with the addition of 41 from a separate project the sample size is too small compared to the number of variables potentially affecting community composition.
Outcomes and methods of analysis (inc effect size, CIs for each outcome and significance)	Primary outcome measures	% cover of species within quadrat Main data set: pH, peat depth, conductivity, altitude, aspect, slope, veg height, saturated or not (no explanation); distances to nearest: burn; older burn/recovering veg.; grip; significant change of slope; area of eroding peat; cover of peat-building Sphagna (combined cover of *Sphagnum capillifolium*, *S. magellanicum* & *S. papillosum* = S) plus *Eriophorum vaginatum* (E) in 20m^2

		NVC type Data subset (41 quadrats): soil moisture, litter depth, extractable ammonium, nitrate, sulphate, calcium, magnesium, copper, lead, zinc & aluminium.
	Secondary outcome measures	Frequency of occurrence of all 13 Sphagna 'Peat Building Index' (bog condition) = S + (E/4) Main data set: Sphagnum species richness; plant species richness Data subset: Shannon diversity index
	Follow-up periods	None
	Methods of analysis	Initial DCA CCA with independent variables (full model and most parsimonius model) Linear regression for individual Sphagnum species against more influential environmental parameters. Generalised linear modelling with Poisson error distribution for the relationship between continuous environmental variables and overall plant species richness & Sphagnum species richness. Non-parametric correlation (Kendall's Tau) between each of the two measures of richness and ordinal variables Linear regression for PBI and overall plant species richness & Sphagnum species Non-parametric correlation (Kendall's Tau) for PBI and ordinal variables
Results		For the main data set the full CCA model explained only 17% of variation in quadrat composition while the most parsimonius model achieved only 9% - the environmental variables used are therefore of little value in explaining Sphagnum abundance or

		occurrence. *Sphagnum rubellum* & *S. papillosum* were the most widespread peat-forming species M19 *Calluna vulgaris-Eriophorum vaginatum* mire was the most frequent NVC type There was a significant negative relationship between total plant species richness and vegetation height (P=007 with outlier removed), and a positive relationship with altitude (P = 0.03); PBI was related significantly to peat depth. Sphagnum species richness was positively related to peat depth (P<0.001) Of the 8 species tested, all but *S. palustre* showed a significant positive relationship with peat depth, and this was particularly strong for *S. capillifolium* and *S. papillosum*. For the data subset, the full CCA model using 13 variables explained 36% of the variation, with axis 1 most clearly related to moisture and axis 2 to pH/litter depth; the most parsimonius model indicated that 6% of variation was attributable to moisture content. It is suggested that some Sphagnum species are more tolerant of management such as burning that reduces peat moisture content and litter depth,
Notes	Limitations identified by author	Possible species oversights, and *Drosera* specifically, as sampling was autumn/winter; this is unlikely to alter the results with respect to Sphagna. Use of walkover/correlation rather than direct impacts over time
	Limitations identified by review team	Small number of samples of small physical size for the size of the total area encompassed. Use of a transect within the sampling plot – not justified in the text Grazing pressure not considered. Species response to management will vary with geographic location therefore the

		outcomes of the study are likely to be specific to the North Pennines, as acknowledged indirectly in the report.
	Evidence gaps and/or recommendations for further research	More direct research into the impact of burning Wider research into the general responses of Sphagna to management activities across the UK peat resource.
	Sources of funding	North Pennines Area of Outstanding Natural Beauty Partnership's Peatscapes project

Evidence Table

Name of Evidence Review:	Natural England Uplands Evidence Review
Name of Review Topic:	What are the effects of managed burning on the maintenance and restoration of upland peatland biodiversity and the provision of ecosystem services?
Review Question(s)	What are the effects of managed burning of upland peatlands on carbon sequestration and storage, either directly or indirectly through changes in vegetation composition and structure?

Study details	Authors	Orwin, K.H. & Ostle, N.J.
	Year	2012
	Aim of study	To investigate how fire frequency affects the role of 3 different moss species in peat carbon cycling.
	Study design	Randomised (partially) Control Trial
	Quality score	1+
	External validity	EV+
Population and setting	Source population	North England, North Pennines, Cumbrian uplands
	Eligible population	*Calluna-Eriophorum* blanket mire
	Inclusion and exclusion criteria	Area within defined long term experimental plots subject to experimental burning – not stated explicitly that this is confined to the fenced plots but this is assumed.
	Setting	Moor House NNR, Hard Hill burning experiment

Methods of allocation to intervention/control	Methods of allocation	Pre-defined burning treatment in ungrazed section of 4 replicate long-term experimental blocks: 2 x Burn treatments plus no burn randomised within fenced section of each block 2 patches of each moss & 2 bare patches defined within each plot
	Intervention description	10yr burn rotation - 7th burn in 2007 20yr burn rotation – 3rd burn in 1996 Litter decomposition beneath patches of 3 different moss species (*Sphagnum capillifolium*, *Hypnum jutlandicum* & *Plagiothecium undulatum*)
	Control/comparison description	No burn – burnt in 1954 only Litter decomposition within surface litter layer on bare ground.
	Sample sizes	*In situ - Net Ecosystem Exchange (of C) & Standard litter decomposition* *Split-plot design* 4 x blocks (random effect) x 3 burn treatments (main plot) x 4 species(3 mosses & bare ground, sub-plot) = 48 *Ex situ – moss litter decomposition and C:N ratios* 4 x blocks (random effect) x control plots x 3 moss species (burn treatment and moss species both main effects) = 12 4 x blocks x 10yr plot x 1 species = 4 4 x blocks x 20yr plot x 2 species = 8 Total = 24
	Baseline comparisons	For NEE & *ex situ* moss litter decomposition/C:N ratios = No burn plots – steady state community

		In situ decomposition of standard litter sample = No burn plots & bare ground patches – decomposition at steady state and independent of surface moss species
	Study sufficiently powered	*In situ* study reliant on sampling a single patch for each aspect, which leads to lack of power for fire effects. *Ex situ* study contains missing values and is based on single bulked litter sample.
Outcomes and methods of analysis (inc effect size, CIs for each outcome and significance)	Primary outcome measures	*In situ* CO_2 flux g/m^2/h under natural illumination and in artificial darkness Initial moisture content of *Eriophorum vaginatum* litter Oven dry weight of litter 1yr after burial *Ex situ* C and N concentrations of initial and decomposed litter Initial moisture content of litter for each of 3 moss species Oven dry weight of litter 1yr after burial
	Secondary outcome measures	*In situ* Moss photosynthetic rate NEE % mass lost from litter bags following 1yr period of burial *Ex situ* C:N ratio

		% mass lost from litter after 42 weeks
	Follow-up periods	CO_2 flux measured in May, June & July 2009 Litter left *in situ* for 1yr Litter left for 42 weeks for *ex situ* study
	Methods of analysis	Split-plot ANOVA for *in situ* study Burn treatment = main plot, moss species = sub-plot, block = random effect Means investigated using least significant difference Normal ANOVA for *ex situ* study Block = random effect, species & burn treatment = main effects
Results		NEE was higher in 20yr than 10yr plots in May, because photosynthetic rate was lower here ($p<0.05$ for both) Mosses were a net source of CO_2. Sphagnum exhibited lower NNE compared to the other mosses and bare ground: the gross respiration of Sphagnum was lower than for other mosses & peat in June, while photosynthesis was higher in May ($p<0.05$ for both). Soil temperature at 5cm depth was higher in the 10yr compared to 20yr and no burn ($P<0.0585$ & 0.001); and higher under bare peat than moss ($p<0.05$). PAR was highest in the 10yr burn in June (no precision quoted) *Ex situ* <u>No burn sites only</u>: Moss litter decomposition rate and % C loss was highest for *Plagiothecium* ($p<0.001$),

		for which C:N ratio was lowest ($p<0.05$) <u>Considering Burn treatments</u> The % C loss from Sphagnum was less in the 10yr compared to 20yr and no burn For both *Sphagnum* and *Plagiothecium* % C and mass loss was higher in the no burn than in 10yr or 20yr burn
Notes	Limitations identified by author	Only considered NEE over a 3 month period: other authors suggest non-vascular plants may be photosynthetically active over a much longer period of the year, which would make contribution to C-sequestration higher than suggested.
	Limitations identified by review team	Lack of detail for some aspects of the study makes it difficult to assess validity with full confidence, particularly the characteristics and 'purity' of individual species' patches. Definition of 'litter' component of above ground biomass is problematic and may be a source of error disproportionately among the species because of their different morphologies.
	Evidence gaps and/or recommendations for further research	Extend the duration of CO2 flux study to encompass a longer growing season and periods of the year when, for non-vascular species, water deficit is less likely. Increase replication within plots for a single species as a means of increasing power of detecting fire effects.
	Sources of funding	Not acknowledged

Orwin & Ostle (2012) used the long term burning experiment on high altitude *Calluna-Eriophorum* blanket peat at the Hard Hill site, within Moor House NNR, to study the role of mosses in carbon cycling after fire. The study focussed on the moss species *Sphagnum capillifolium*, *Hypnum jutlandicum* and *Plagiothecium undulatum*, which have a wide ecological tolerance and which are ubiquitous among the burn treatment plots.

Two patches of each moss species and two bare patches of peat were selected in each of the 3 burn treatments (no burn, 20yr and 10yr burn rotation) across the 4 replicate blocks at the site. Carbon dioxide flux was measured by IRGA in one patch both in full natural illumination and with light excluded artificially. This provided an estimate of moss photosynthetic rate and gross respiration from which Net Ecosystem Exchange was derived. Total photosynthetically active radiation (PAR) at the surface of the patch and soil temperature at 5cm depth were also quantified. A mesh bag containing a standardised litter sample of *Eriophorum vaginatum* was buried beneath the surface in the second patch, where it was left for a year. The loss in mass was determined, adjusting for initial moisture content.

Litter from all three moss species was collected and allowed to decompose for 42 weeks within sealed petri dishes on top of peat samples but separated by fine mesh. Peat samples were obtained from the respective plots of origin for each litter sample and maintained within the petri dish at constant moisture levels equivalent to field conditions. Insufficient biomass was available from some plots for a fully balanced design. The C:N ratio of the litter was determined at the start and finish of the experimental period and the loss in mass was determined as for the *in situ* study.

The moss species were primarily responsible for differences in the parameters quantified, with very few burn effects detected in either the *in situ* or *ex situ* study. In general, mosses were shown to be sources of CO_2 during the short period of the investigation but *Sphagnum* had the greatest propensity to sequester carbon in certain months; this could be attributed to periods when photosynthetic rate was higher and/or respiration rate lower than for other the species.

Soil temperature at 5cm depth was higher beneath bare peat and for 10yr burn plots, and PAR was highest for this treatment in June. The rate of litter decomposition was not affected by burn treatment or moss species.

Litter characteristics differed among moss species with *Plagiothecium* having the lowest C:N ratio and decomposing most rapidly under controlled conditions. Litter of both *Sphagnum* and *Plagiothecium* lost mass and carbon faster on peat from no burn compared to burnt plots, whilst least C was lost by *Sphagnum* in the 10yr burn. Comparing initial and final C:N suggests that litter characteristics other than C:N ratio, and which affect the rate of litter decomposition, change in response to disturbance per se.

Predicting the effect of fire on peatland c-cycling requires knowledge of the species composition of the community and the extent to which species traits affecting c-sequestration vary autogenically and allogenically.