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)	h) What are the extent, frequency, practice and type of managed burning (including 'cool burning') on upland peatlands (including in relation to designated sites and water catchments)?

Study details	Authors	Penny Anderson Associates Ltd, Natural England Commissioned Report NECR089
	Year	2012
	Aim of study	Mapping the status of upland Peat, in England, using aerial photographs
	Study design	2: survey/census/correlation
	Quality score	2++
	External validity	EV++
Population and setting	Source population	Upland deep peat
	Eligible population	Deep peaty soils (>40cm depth) within the moorland line. That is areas of Soil Association mapping where the dominant series have more than 40cm of peaty surface material, where British Geological Survey (BGS) drift mapping indicated peat deposits, and where the BAP habitat inventory mapping indicated blanket bog habitat within the Moorland Line. This provides a map of deep peaty soils under moorland vegetation.
	Inclusion and exclusion criteria	Included all mapped areas within this original dataset, but excluded any area <1ha (the minimum mapping unit) and 1 Afforested – Planted woodlands;

		2 Wooded – Natural woodlands; 3 Cultivated – Arable or horticultural land; 4 Improved grassland – Agriculturally improved grassland; 5 Removed – as a product of other development ie quarry, building, etc; and, 6 Extracted – current peat extraction.
	Setting	English, upland, moorland deep peat
Methods of allocation to intervention/control	Methods of allocation	Looked at all English, upland, moorland deep peat
	Intervention description	Looked for Burnt Gripped Hagged/gullied (eroded) Bare Peat cuttings (where visible) And combinations of these. Initially they also looked for Purple Moor grass dominated land but discarded this classification as it was not possible to detect on aerial photographs flown in the summer
	Control/comparison description	No real control/comparison as it was looking to map all areas affected within the population
	Sample sizes	No sampling for overall mapping (sampling used to allocate points for ground truthing of aerial photographic interpretation)
	Baseline comparisons	Essentially this captures a period in time and arguably sets a baseline

	Study sufficiently powered	Looks at whole of sampling area ie all upland deep peat in England. Some issues with quality of original datasets explained and will mean that there may be some areas included with <40cm of deep peat but also some areas with >40cm deep peat that were not on the original maps. Ground truthing of aerial photographic interpretation has been done robustly. This suggests that the overall interpretation rate at 61.4% is not good. However reasons are provided for this including size of mapping unit and general complexity of often having more than one effect acting on a particular area of moorland. As most of the problems described refer problems with things like overlaps with bare ground, hagging and erosion, the burning element of this report seems likely to be the strongest. This only captures a point in time when the aerial photograph was flown and will change over time, but this is likely to be a strong description of overall levels of burning in any area.
Outcomes and methods of analysis (inc effect size, CIs for each outcome and significance)	Primary outcome measures	Maps of upland, deep peat showing **Burnt** Gripped Hagged/gullied (eroded) Bare Peat cuttings (where visible) Shows how much is burnt and where.
	Secondary outcome measures	Discussion of differences in intervention/management in different parts of the country, potentially down to individual moors. Seem to have picked up where moorland restoration is ongoing, but this has not been separated out. So gripped includes areas that are still drained and those areas which are being restored. As moorland restoration is relatively new this means this creates a useful baseline
	Follow-up periods	N/A

	Methods of analysis	N/A
Results		Map showing where areas of upland deep peat are burnt in England (also gripped, hagged, eroded etc) 55.8% (178,882 ha) of total moorland deep peat is both unburnt and otherwise unmanaged. 24% (76,991 ha) of moorland deep peat is burnt, this may be combined with other management such as gripping etc. Limited analysis of this data is provided by the report, because as they explain it could be used in so many ways. There is discussion of regional issues and the differences between them.
Notes	Limitations identified by author	This data set can only be as good as the original peat layer polygons. Issues with the peat layer boundary were found including irregular and unaccountable holes in the peat layer, whilst the vegetation is identical to that abutting it. There are also issues about areas missing from the peat layer which are managed and vegetated in the same way as the adjoining land within the peat layer. The ground truthing visits included an assessment of peat depth. The original map should only include areas of deep peat, (> 0.40m deep), it is surprising that 27% of ground truthing sites have shallower peat . There is no reason to suppose that the sample sites are atypical of the whole data set and, therefore, this finding has serious implications for the definition of areas included and excluded from the peat layer. The ground truthing exercise found issues with the aerial photographic interpretation, with only a 61.4% reliability for the whole data set. However for the burnt element of this mapping the only issue identified was that the burning pattern had altered since the aerial photograph had been taken. This is to be expected for any exercise that looks at a point in time, and perhaps it would be reasonable to suggest that the map of burnt peat is likely to be a lot more accurate.
	Limitations identified by review team	Possibly the minimum mapping unit of 1 ha is a little large for using at the individual site level, but is reasonable for a national map. Possibly the fact that aerial photography was flown over an extended period Epoch 1 (full coverage 1999-2004) and Epoch 2 (partial coverage 2003-2008), may make this difficult to

		truly describe as a point in time, although each photograph will only represent that one point in time when it was flown. It may make it difficult to use this as a baseline if there is no information on exact ages of photography?
	Evidence gaps and/or recommendations for further research	Use the information gathered to improve the robustness of the original dataset and highlight any areas where perhaps more detailed survey might be required. “The maps help our understanding of English peatland and can be used to enable improved estimations of greenhouse gas flux and carbon storage and delivery of other ecosystem services, as influenced by peatland status and management. The maps can also inform research and restoration priorities, provide a baseline to which future assessments of peatland status can be compared, and help to underpin policies to support improvements to our management of peatlands.” Could use this map to compare levels of burning and the other interventions between SSSI and non-SSSI land. It could look at water catchments and compare to water quality data. It could be used at an individual site level to say that one moor is being burnt more heavily than another, for instance for negotiating with landowners, this could be very useful evidence to provide for land management teams. It could also be compared to other data such as grouse bags or RSPB bird monitoring to see if higher levels of burning are really having an impact on these elements, positive or negative.
	Sources of funding	Natural England, Game Conservancy Trust, Water Authorities.

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	Pearce Higgins, JW & Grant, MC
	Year	2006
	Aim of study	To determine how variation in vegetation characteristics affects breeding bird abundance on moorlands.
	Study design	Correlation
	Quality score	2+
	External validity	EV+
Population and setting	Source population	Moorland in N England and S Scotland
	Eligible population	72 plots in S Scotland and 13 in N England
	Inclusion and exclusion criteria	Study plots were located by random sample of sites from the National Countryside Monitoring Scheme stratified by heather cover supplemented by a random sample of plots using a 1990 heather map of Scotland.

		Access to some sites was refused so the final sample was made up with an additional 32 plots selected non-randomly where access was possible.
	Setting	Upland moorland with heather dominated vegetation.
Methods of allocation to intervention/control	Methods of allocation	1 – 3 $2km^2$ survey plots were allocated per study plots.
	Intervention description	n/a
	Control/comparison description	n/a
	Sample sizes	72 $2km^2$ survey plots.
	Baseline comparisons	n/a
	Study sufficiently powered	Multivariate analysis of complex data set.
Outcomes and methods of analysis (inc effect size, CIs for each outcome and significance)	Primary outcome measures	Numbers of breeding pairs for sample plots. Numbers of meadow pipit and skylark in 1km line transect. Vegetation measures (height, species ground cover, vegetation density) Abiotic measures – presence of hagging, muirburn, soil type, climate data, game keeper density. Presence of carrion crows were used as a measure of predator abundance.
	Secondary outcome measures	None
	Follow-up periods	n/a

	Methods of analysis	Multivariate analysis through 3 stage minimum adequate models.
Results		Nine bird species were studied in detail – these showed substantial variation in response to vegetation composition and structure after accounting for non-vegetation variables. Red grouse and stonechat were associated with heather but both favoured some heterogeneity in cover and the latter was associated with tall vegetation. Snipe and curlew were most abundant where vegetation structure was heterogenous. Skylark and golden plover were associated with short vegetation, especially short grass and short dwarf shrub cover. Wader species were positively associated with plant species indicative of wet conditions. Whinchat were associated with dense vegetation especially bracken. No strong vegetation effects were noted for wheatear. Meadow pipit was not affected by structure of vegetation but favoured grass-heather mixes.
Notes	Limitations identified by author	Access restrictions affected sampling strategy. Autocorrelation between variables producing problems for analysis and interpretation.
	Limitations identified by review team	As above – study does not include major grouse moor areas of the Pennines so relevance to such moorland may be questioned.
	Evidence gaps and/or recommendations for further research	Extend to further upland areas including the main grouse moor areas. Experimental manipulation e.g. in paired sample plots where treatments can be reversed. For the purposes of this review a similar study stratified for deep peat rather than heather cover, to include suitable sampling of grouse and non-grouse moors. It might also include as a factor SSSI condition.

	Sources of funding	RSPB

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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	Picozzi, N
	Year	1968
	Aim of study	To compare grouse bags with
	Study design	2: correlation
	Quality score	2+
	External validity	EV+
Population and setting	Source population	Grouse moors in Scotland.
	Eligible population	26 shooting estates (25 in NE Scotland, 1 in NW Sctoland) where grouse bag records were available.
	Inclusion and exclusion criteria	Data collected from moors where grouse bags were known. No explanation about how this cohort was established.
	Setting	Calluna dominated moorland managed by burning in Scotland.

Methods of allocation to intervention/control	Methods of allocation	Data collected from moors where grouse bags were known.
	Intervention description	Controlled burning.
	Control/comparison description	None.
	Sample sizes	26 shooting estates with approx 40km2 moorland sampled. Vegetation sampled at approx. 60m intervals along transects.
	Baseline comparisons	None.
	Study sufficiently powered	Not randomised but multiple regression used – correlation coefficient explains 67% of variation in grouse bags in terms of mean area of fires, number of recent fires/km and index of base status.
Outcomes and methods of analysis (inc effect size, CIs for each outcome and significance)	Primary outcome measures	Relationship of grouse bags to intensity of burning management. Relationship of grouse bags to base status of soil parent material.
	Secondary outcome measures	None.
	Follow-up periods	None.
	Methods of analysis	Multiple regression.
Results		Grouse bags are positively related to base status of soil parent material. ($P<0.005$) Grouse bags are positively related to the number of recent fires. ($P<0.001$) Bags were negatively correlated with mean area of fires but not significantly so. ($P<0.2$)

Notes	Limitations identified by author	Advantages of different fire sizes cannot be fully assessed.
	Limitations identified by review team	Lack of sampling and failure to explain the origin and limitations of the sample. Exclusion of older stands of heather from analysis as areas of these were difficult to estimate. Estimates of stand area likely to be subject to (unknown) error. No account taken of depth of peat ('insulates' surface vegetation from drift'). Site characteristics inadequately described and controlled for.
	Evidence gaps and/or recommendations for further research	These findings support experimental conclusions and are now well known. It would be useful to know whether these findings apply equally to dry moors and those on blanket bog.
	Sources of funding	Not reported but assumed to be Nature Conservancy.

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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)	

Study details	Authors	PITKANEN, A. *et al*.
	Year	1999
	Aim of study	To determine the fire history and the effect of fires on the long-term (apparent) rate of carbon accumulation (LORCA) in the Patvinsuo National Park *raised mire complex* in eastern Finland.
	Study design	2: palaeoecological study. Could be regarded as a case-study.
	Quality score	2+
	External validity	EV-
Population and setting	Source population	Finnish peatlands.
	Eligible population	Patvinsuo National Park *raised mire complex* in eastern Finland.
	Inclusion and exclusion criteria	NR
	Setting	Patvinsuo National Park *raised mire complex* in eastern Finland.

Methods of allocation to intervention/control	Methods of allocation	NA
	Intervention description	Past fire events.
	Control/comparison description	NA
	Sample sizes	Stratigraphic and pollen analyses on 98 peat cores from one Finnish site.
	Baseline comparisons	NA
	Study sufficiently powered	NA
Outcomes and methods of analysis (inc effect size, CIs for each outcome and significance)	Primary outcome measures	Long term apparent carbon accumulation values (LORCA).
	Secondary outcome measures	Charcoal horizons and fire frequency, carbon accumulation and loss.
	Follow-up periods	NA. Peat samples dated back to c.11,000 BP.
	Methods of analysis	Non linear regression analysis using the method of least squares.
Results		The peat cores were characterised by a large number of charcoal layers and the age of the basal peat varied between 57 and 10,500 years. Mire fires slowed down the progress of vertical peat accumulation and resulted in “great carbon losses”. The average LORCA in the Patvinsuo cores (9.2 ± 1.0 (SE) g m^{-2} yr^{-1}) was lower compared to the average for all mires in the southern half of Finland (17.7 ± 0.6 (SE) g m^{-2} yr^{-1}). The average rate of carbon loss in the Patvinsuo mires was 9.5 ± 1.0 (SE) g m^{-2} yr^{-1} and the mean carbon loss in an individual fire was estimated to be 2.5 kg m^{-3}.

Notes	Limitations identified by author	
	Limitations identified by review team	
	Evidence gaps and/or recommendations for further research	
	Sources of funding	Academy of Finland to Kimmo Tolonen.

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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)	a, c & d

Study details	Authors	Ramchunder, Brown & Holden
	Year	2009
	Aim of study	To review the hydrological, physicochemical and ecological effects of rotational burning and to hypothesise likely effects of burning of ecosystems and illustrate these with a schematic model
	Study design	2: Quantitative correlation
	Quality score	2+
	External validity	EV+
Population and setting	Source population	Upland blanket peats
	Eligible population	N/A
	Inclusion and exclusion criteria	Review of research of sites subject to rotational burn or no burning intervention

	Setting	UK uplands (predominantly N. England) (where knowledge from UK peatland systems is lacking, reference is made to international studies
Methods of allocation to intervention/control	Methods of allocation	N/A
	Intervention description	Managed burning (review of literature – details of intervention (size/intensity etc) varied between research assessed)
	Control/comparison description	Compared to 'intact' peatland river basins ('intact' used to signify those areas in which blanket peats remain relatively undisturbed)
	Sample sizes	N/A
	Baseline comparisons	N/A
	Study sufficiently powered	N/A
Outcomes and methods of analysis (inc effect size, CIs for each outcome and significance)	Primary outcome measures	Stream discharge, suspended sediment concentration, electrical conductivity, pH and stream ecology (resource base – detritus and primary producers/functional feeding groups – grazers, shredders, collector-filterers, collector-gatherers, invertebrate predators and fish)
	Secondary outcome measures	N/A
	Follow-up periods	N/A
	Methods of analysis	Review of literature, and production of schematic diagram
Results		Burned catchments will have a greater proportion of land exposed to wind and water erosion, and induced hydrophobicity, meaning faster, flashier run-off and higher peak flows will be observed. Suspended sediment concentrations in the burned catchment

		may also be higher *cf* an intact catchment. Hydrophobic soils in the burned catchment will result in lower infiltration rates, and therefore the initial increase in electrical conductivity may be moderated, and pH is unlikely to alter significantly. Burning is expected to increase the concentrations of suspended peat detritus in stream systems, and this will smother primary producers when deposited. The abundance of grazers in the stream system is likely to be reduced due to smothering of the substrata with sediment and a lower abundance of food sources. Higher concentrations of suspended peat detritus may result in a higher abundance of collector-filters. The greater deposition of fine organic sediment will reduce habitat heterogeneity and lack of prey items will have negative knock-on effects on invertebrate predators and fish.
Notes	Limitations identified by author	The lack of stream ecological studies in relation to peatland management means hypothesised responses were based on general freshwater biological knowledge
	Limitations identified by review team	Much evidence presented in literature review refers to very dated research (e.g. 1971/1978/1983/1984/1985), and based on a single reference. Whether the study reviewed robustness of research in cited papers is not explicit
	Evidence gaps and/or recommendations for further research	On-going research to test conceptual model based on observations from UK uplands Research to fill knowledge gaps in model – particularly lack of data on peatland river ecosystem response to managed burning
	Sources of funding	NERC, North Pennines AONB and Natural England

Following a review of the literature, Ramchunder et al (2009) propose a schematic model to link key changes in upland peatland systems following rotational burning. The diagram represents potential impacts on the storm hydrograph, suspended sediment transport, stream physicochemistry (specifically electrical conductivity and pH) and the biota of moorland streams.

The authors propose that burned catchments will have a greater proportion of land exposed to wind and water erosion, and induced hydrophobicity, meaning faster, flashier run-off and higher peak flows will be observed. Suspended sediment concentrations in the burned catchment may also be higher *cf* an intact catchment. Hydrophobic soils in the burned catchment will result in lower infiltration rates, and therefore the initial increase in electrical conductivity may be moderated, and pH is unlikely to alter significantly. Burning is expected to increase the concentrations of suspended peat detritus in stream systems, and this will smother primary producers when deposited. The abundance of grazers in the stream system is likely to be reduced due to smothering of the substrata with sediment and a lower abundance of food sources. Higher concentrations of suspended peat detritus may result in a higher abundance of collector-filters. The greater deposition of fine organic sediment will reduce habitat heterogeneity and lack of prey items will have negative knock-on effects on invertebrate predators and fish.

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Review Question(s)	

Study details	Authors	Ramchunder *et al*. [Also Ramchunder 2010 and Brown *et al*. 2009.]
	Year	2013
	Aim of study	A study of the effects of burning *peatland* catchments on benthic invertebrates in headwater streams in a sample of sites in the Pennines. Brown *et al*. (2009) undertook a pilot study to compare the aquatic invertebrate communities of three second-order streams in upland peatland catchments subject to controlled burning with those of the Moor House NNR catchment in the North Pennines which has no burning and minimal grazing. Ramchunder *et al*. (2013) sampled a selection of three burned and three unburned sites over four seasons and five further examples of each were sampled on a single occasion.
	Study design	2: correlation study/survey.
	Quality score	2++
	External validity	EV+
Population and setting	Source population	Pennine peatlands.

	Eligible population	North Pennines and Peak District blanket bog
	Inclusion and exclusion criteria	NR
	Setting	Pennine blanket bog.
Methods of allocation to intervention/control	Methods of allocation	NA
	Intervention description	Managed burning.
	Control/comparison description	Unburned sites (3).
	Sample sizes	Three burned and three unburned sites over four seasons and five further examples of each were sampled on a single occasion. For the 3v3 survey, streams were sampled seasonally across 3–4 days per quarter (2007: September 11–13, December 19–21; 2008: March 4–7, June 10–13, September 16–18). The 5v5 survey was concurrent with the September 2008 survey.
	Baseline comparisons	NA
	Study sufficiently powered	NR, but sample sizes large.
Outcomes and methods of analysis (inc effect size, CIs for each outcome and significance)	Primary outcome measures	At each site macroinvertebrates were sampled using a Surber sampler and identified to species or higher taxonomic group (e.g. Diptera to genus, Oligochaetes to class). Species data were used to calculate measures of community structure (total abundance, relative abundance of functional feeding groups, taxonomic richness, diversity index and taxonomic dominance (Berger Parker Index).
	Secondary outcome measures	Sixteen environmental factors were measured.

	Follow-up periods	
	Methods of analysis	Data were analysed show differences in environmental factors and biota between burned and unburned sites and to explore the species – habitat relationships. Macroinvertebrate community structure was summarized using five measures: (i) log10 (total abundance+1) expressed as the total number of individuals per m^2; (ii) taxonomic richness; (iii) relative abundance of FFGs assigned; (iv) 1/Simpson's diversity index; and (v) taxonomic dominance (D) estimated using the Berger–Parker index. Repeated-measures ANOVA and one-way ANOVA were repeated for the macroinvertebrate community metrics for the 3v3 and 5v5 surveys, respectively.
Results		Both 3 x 3 (seasonal) and 5 x 5 (single sample) surveys showed burning was linked to changes in stream environmental variables (e.g. increases in suspended sediment concentration, Fine particulate organic matter, Al, SO_4, NO_3, DOC and smaller D_{50}). This suggests that burning can increase the vulnerability of soil to physical erosion resulting in higher sediment yields. Significantly higher concentrations of DOC were found in burned catchments and this study suggests that burning is a local driving factor in DOC production. There were significant differences in community richness, diversity and dominance and community composition in contrast to artificially drained catchments where drainage was shown to have no such effect. There were lower abundances of herbivores and predators in burned sites and there was a shift from communities dominated by mayflies and large predatory stoneflies to communities dominated by Diptera (especially Chironomids and Simulids) and smaller stoneflies at burned sites. Higher amounts of Suspended Sediment Concentration, Fine Particulate Organic Matter in burned sites were considered to be likely to drive these effects. The generality of these results is difficult to determine as there are few other published studies into stream responses to heather burning, but the findings here are similar to those found from studies of the effects of wildfire in other locations.

Notes	Limitations identified by author	"It may be that prescribed burning also affects other aquatic organism groups (e.g. algae, microbes, fish) and there is a clear need for more work in this area, particularly given the apparent recent increase in burn frequency and encroachment of prescribed burning onto larger areas of blanket bog (Yallop *et al*. 2006b). We focused solely on headwater second-order streams and therefore need to examine the effects of upland prescribed burning further downstream to determine the spatial extent of burning impacts."
	Limitations identified by review team	
	Evidence gaps and/or recommendations for further research	Extension to more sites and other aquatic groups.
	Sources of funding	This research was funded by a NERC studentship (NER/S/A/2006/14151) with CASE support from Yorkshire Water, and additional funding from the North Pennines AONB Peatscapes project (ED1113347) and Natural England (SAE03-02-051).

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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	Ross, S., Adamson, H. & Moon, A.
	Year	2003
	Aim of study	To evaluate management techniques for controlling *Molinia* and enhancing *Calluna* in wet heath in northern England..
	Study design	Randomised (partially) Control Trial – split plot design
	Quality score	1+
	External validity	EV+
Population and setting	Source population	North England, Northumberland uplands
	Eligible population	Dwarf shrub-dominated communities
	Inclusion and exclusion criteria	Areas within ESA subject to sheep grazing at recommended stocking rates and where enhancement of *Calluna* (and concomitant suppression of *Molinia*) is desired.
	Setting	*Scirpus cespitosus-Erica tetralix* wet heath, NVC type M15.

Methods of allocation to intervention/control	Methods of allocation	2 Areas selected where sheep grazing was at two contrasting rates prescribed under ESA Within each Area, 3 x blocks were designated in target M15 wet heath, within which 4 x plots were established in a block and treatments assigned within at random.
	Intervention description	Single burn in April 1996 Single burn in April 1996 followed by cutting to 8cm height in July 1996 Single burn in April 1996 followed by herbicide application in July 1996 Sheep grazing @1.5 or 0.66ewes/ha
	Control/comparison description	No burning, cutting or herbicide. Sites stated as no burn for >20 yrs by Stewart et al. (2004) Sheep grazing @1.5 or 0.66ewes/ha
	Sample sizes	**For each of the 2 main plots**: 3 x blocks x 4 treatments x 5 quadrats per sampling occasion: *Top cover, Frequency & Dominance (static)* = single value (no. out of 100 cells) = 3 x 4 x 5 = 60 per occasion (1997-1999, or 1998-1999) *Change in Dominance* For 4 x categories of change from *Calluna* to another key species, plus *Molinia* to *Calluna*: Determined for 3 x 4 x 5 samples between 1995, 1998, 1999 Determined for each of 3 main vegetation types present pre-treatment between successive recording periods (1995 to 1998; 1998 to 1999). ANALYSIS OF DOMINANCE DATA IS NOT ENTIRELY CLEAR FROM THE METHOD, WHICH

		SUGGESTS ONLY CHANGES AMONG CATEGORIES FOR *CALLUNA* WERE CONSIDERED BUT RESULTS IMPLICATE ANALYSIS OF STATIC DOMINANCE DATA FOR *MOLINIA* AND *CALLUNA* ON EACH SAMPLING OCASSION
	Baseline comparisons	**For each of the 2 main plots**: Pre-treatment *Top cover, Frequency & Dominance* = single value = 3 x 4 x 5 = 60 in 1995 (pre-treatment) Post-treatment Control with no management treatment, all 3 measures = 3 x 1 x 5 = 15 per occasion (1997-1999, or 1998 & 1999)
	Study sufficiently powered	Statistically rigorous design with adequate replication, to an extent not normally seen in field experiments.
Outcomes and methods of analysis (inc effect size, CIs for each outcome and significance)	Primary outcome measures	% cover of all species in 1mx1m quadrat (assessed from 100 sub-cells) % frequency of all species in 1mx1m quadrat (assessed from 100 sub-cells) 'Dominance' = no. out of 100, 10cm x 10cm sub-cells in which each species is the dominant component
	Secondary outcome measures	*Rate of change of Dominance data* No. of cells in which there was a change in the dominant species between successive recording events for: *Calluna* to *Molinia* *Calluna* to *Deschampsia flexuosa*

		Calluna to *Carex nigra* *DCA output* Vegetation types identified from DCA & fuzzy clustering used to group quadrats then used as part of analysis of frequency and dominance data.
	Follow-up periods	3 years post-treatment for all plots
	Methods of analysis	*Main plots analysed separately* DCA for baseline top cover data Fuzzy clustering to classify vegetation types present in each Area at baseline Categorisation using NVC format of baseline top cover and frequency data for groups identified by fuzzy clustering to describe main vegetation types. Repeated measures ANOVA for frequency data, using multiple comparison tests. Kruskal-Wallis/Friedman ranked ANOVA for dominance data
Results		**DCA and fuzzy clustering** Baseline Area 1: 3 vegetation types – *Molinia*-dominated; *Calluna* dominated; mixed heath Baseline Area 2: 3 vegetation types – *Molinia[and Deschampsia*]-dominated; *Calluna-Eriophorum* [both *E. vaginatum* & *angustifolium*]; mixed heath Between 1995-1997 and 1998-1999 vegetation groups shifted across ordination space in response to treatments, and some showed partial reverse movement. Some shifts could be related to increasing dominance of *Molinia;* control quadrats showed least movement. **Frequency data**

		1.5 ewes/ha – Molinia in ca. 70% of cells When initial % of *Molinia* was included as a covariate, there was significantly less *Molinia* only when herbicide was applied after burning compared to burning alone (p<0.05? – difference among treatments was p=0.032 but precision used for multiple comparisons is not quoted) Burning reduced the frequency of *Calluna* for all treatments: time trends were significant but not linear being lower in post- compared to pre-treatment but with a temporary peak in 1998. Burning had negligible impact on above ground *Calluna* biomass where *Molinia* dominated the vegetation initially (differences in burn characteristics?). *0.66 ewes/ha Molinia in 50% of cells* No difference in *Molinia* among treatments or over time – recovery from herbicide was rapid. Burning reduced the frequency of *Calluna* for all treatments, but this showed a recovery from 1998 on. **Dominance** In 1995 in both Areas, plots started with a similar dominance of *Molinia* and *Calluna*: burning reduced dominance of *Calluna* in all managed plots. *1.5 ewes/ha* TREND ONLY for burning & herbicide to suppress a slight increase in *Molinia* dominance between 1998 & 1999; the increase between 1995 & 1998/1999 was significant for burning & cutting only. *0.66 ewes/ha* In 1998 dominance of *Molinia* was significantly lower in the control (particularly in

		Molinia –dominated vegetation) compared to all treatments; the trend was the same for 1999. *Calluna* increased in dominance in control plots from 1995 to 1998/1999 **Rate of change in Dominance** Table indicates the nature of significant differences (between adjacent clear cells) in rates of change in dominance. The effects can be explained as follows: *Calluna* is reduced by burning Replacement of *Calluna* by *Molinia* or *Deschampsia* is suppressed by heavier grazing, which appears to favour *C.nigra* instead.

Grazing rate	1.5 ewes/ha		0.66 ewes/ha	
Rate of Dominance change	treatments	control	treatments	control
Mc to Cv	lower		lower	
Cv to Mc			higher	
Cv to C.nigra	higher			
Cv to D. flexuosa			higher	

Notes	Limitations identified by author	Single rather than repeated application of each treatment. Limited time span for assessment of enhancement and altered dominance compared to time for *Calluna* to reach maturity. Grazing behaviour is modified by burning (but not other treatments), with increased targeting of burnt plots at the higher grazing rate.
	Limitations identified by	Use of top cover, which only quantifies dominance in the top most stratum.

	review team	Lack of description for the two main Areas and the spatial relationship of blocks within each Area: the assumption that grazing rate is the site-specific factor affecting vegetation change. Data for grazing impacts (dung/veg height) not presented.
	Evidence gaps and/or recommendations for further research	Similar design but at a larger scale so the effects of small scale heterogeneity are circumvented. Continue for a longer post-treatment period and using multiple applications of treatments (not suited to herbicide use).
	Sources of funding	MAFF

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 and c

Study details	Authors	Shelter, Turetsky, kane & Kasischke
	Year	2008
	Aim of study	To investigate the relationship between sphagnum cover, organic soil depth and soil organic matter stocks.
	Study design	Quantitative observational
	Quality score	2+
	External validity	EV+
Population and setting	Source population	Interior Alaska, Black spruce forests
	Eligible population	2 study sites – both north facing. Characterised by sphagnum fuscum, feather mosses and lichens
	Inclusion and exclusion criteria	Burnt woodland in close proximity to a natural fire break
	Setting	Alaskan black spruce forests

Methods of allocation to intervention/control	Methods of allocation	Observational study, therefore N/A
	Intervention description	Observational study post-wildfire burn
	Control/comparison description	Unburnt sites adjacent to burn plots used as control, assumed to represent mature, pre-fire conditions
	Sample sizes	25 samples per site, 2 pairs of sites
	Baseline comparisons	Unburnt sites used as baseline
	Study sufficiently powered	Power calculation not present, but replicated study with reasonable sample size
Outcomes and methods of analysis (inc effect size, CIs for each outcome and significance)	Primary outcome measures	Ground layer moss/lichen composition Soil core of organic layers to measure moss, fibric, mesic and humic soil Organic matter concentrations determined by mass on ignition
	Secondary outcome measures	N/A
	Follow-up periods	No details provided
	Methods of analysis	ANOVAs
Results		Organic soil depth varied with burn status (ie burned/unburned) (p=0.0001) and surface fuel type (p=0.0001) Soil organic matter stocks showed significant difference between burn status (p=0.0001) and surface fuel type (p=0.0001) Burning was shown to reduce organic soil depth by 55% and organic matter stocks by

		36% Microsites dominated by sphagna had more than a two fold greater soil organic matter stock than microsites dominated by other ground vegetation.
Notes	Limitations identified by author	None
	Limitations identified by review team	Limited size of study – ie only 2 study sites
	Evidence gaps and/or recommendations for further research	-
	Sources of funding	NASA grant, USDA Forest Service and National Science Foundation

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	Smith, A.A., Redpath, S.M., Campbell, S.T., and Thirgood, S.J. (2001)
	Year	2001
	Aim of study	To examine the relationship between habitat characteristics and the abundance of red grouse and meadow pipits using a combined within-estate (Langholm Estate) and among-moors approach.
	Study design	2: correlation
	Quality score	2+
	External validity	EV+
Population and setting	Source population	Upland moors managed for red grouse
	Eligible population	Upland grouse moors where red grouse abundance data were available
	Inclusion and exclusion criteria	No among-moor sites with <40% heather cover (this was not a specific exclusion criteria but a result of the selection of moors managed for grouse).

		Only moors where red grouse abundance data were available (of which there were 69, from which the 36 meadow pipit sites were randomly selected).
	Setting	Langholm Estate for within-estate study and 36 sites (on 29 estates) in three regions (northern England, borders, highland Scotland) for among-moors study
Methods of allocation to intervention/control	Methods of allocation	No intervention/control per se as correlational study. Meadow pipit sites were chosen randomly from the 69 sites where grouse monitoring data were available, for among-moors study.
	Intervention description	No intervention/control per se. Meadow pipit abundance was related to red grouse abundance, gross habitat type (cover of *Calluna*, grass and *Sphagnum*) and burn cover (measured by presence of burnt *Calluna* stalks at point quadrats).
	Control/comparison description	Correlation study. Meadow pipit abundance was related to red grouse abundance, gross habitat type (cover of *Calluna*, grass and *Sphagnum*) and burn cover.
	Sample sizes	Among-moor study: meadow pipits surveyed on 39 sites of $1km^2$, red grouse on 69 sites. Habitat data were collected at 100 point quadrats/$1km^2$ site. Meadow pipits were surveyed using 2x 1km transects/site. Within-estate study: 73 sites (of 25 ha). Habitat type at each site was assessed in $16x4m^2$ quadrats. Meadow pipits were surveyed using 2x 500m transects/site.
	Baseline comparisons	One-off study.
	Study sufficiently powered	Yes
Outcomes and methods of analysis (inc effect size, CIs for each	Primary outcome measures	Grouse and meadow pipit abundance.

outcome and significance)	Secondary outcome measures	Bird species number and diversity.
	Follow-up periods	None
	Methods of analysis	Linear regression models. ANCOVA used to test for differences between within-estate and among-moor datasets.
Results		**Within-estate study:** Pipit abundance declined with increasing muirburn (P=0.004) and heather (P=0.05), suggesting that sites with less burning had more meadow pipits. Increasing amounts of muirburn were associated with more heather (P<0.001) and less grass (P<0.001). No correlation recorded between meadow pipit and red grouse abundance (P=0.6). More grouse were found at higher altitudes (P=0.023). **Among-moors study:** Pipit abundance declined with increasing muirburn (P=0.001), heather (P=0.008), and Sphagnum (P=0.03), suggesting that sites with less burning had more meadow pipits. Muirburn explained 19% of the variation in pipit numbers. In general there were more pipits on drier moors (ie those with lower % cover of *Sphagnum*) with low heather cover and less muirburn. Sites with more heather cover had less grass cover (P=0.001) but the amount of muirburn was not related to the presence of *Calluna* (r=-0.21, P=0.09) or to the amount of grass (r=-0.01, P=0.93) in the among-moor dataset. Moors in the south and east supported more red grouse (when separated by region, there were more grouse on moors in England than Scotland). Looking at the among-moor data, bird species diversity (as determined by Simpson's index) increased on moors with more muirburn (explaining 9% of the variation,

		P=0.002) and increased from west to east. There was no relationship between species number and muirburn. In general more bird species were present on drier moors (with less Sphagnum) with less heather and lower habitat patchiness.
Notes	Limitations identified by author	Meadow pipit abundance data only collected in one year and numbers likely to vary considerably from year to year. Bird abundance data only collected from managed grouse moors where predators are strongly controlled. Because the study was carried out on managed grouse moors, little information on meadow pipit abundance on moors where grass is the dominant vegetation.
	Limitations identified by review team	In relation to the review question, the lack of detailed information regarding the burning regime at each site reduces its value to the review. Thus the measure used to estimate extent of muirburn (point quadrat data on presence of burnt *Calluna* stalks) cannot be related to a particular burning regime (frequency/area etc) and would presumably underestimate burn cover in grassland areas. It only provides information on short-term impacts of burning on meadow pipit numbers. Also, as no detailed information is provided on habitat type, it is not clear whether this study is relevant as it is not clear what proportion of the sites were on peat. No consideration of confounding effects of grazing.
	Evidence gaps and/or recommendations for further research	Need more info on long-term effects of burning on meadow pipits and other species. Also on the feeding and nesting ecology of meadow pipits to understand effects of burning on numbers.
	Sources of funding	Game Conservancy Trust

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	Stone, M
	Year	2006
	Aim of study	To examine the effect of the burning cycle on plant and invertebrate community structure using Calluna life cycle stages as a basis for comparing vegetation change and carabid abundance and diversity as an indicator of change in invertebrate.
	Study design	2: correlation
	Quality score	2-
	External validity	EV+
Population and setting	Source population	Peak District National Park Moorland
	Eligible population	Series of samples in four Calluna growth phases on three moorland study areas.
	Inclusion and exclusion criteria	Plots subject to controlled burning selected to represent a range of ages since the last burn.

	Setting	Upland moorland on deep peat with heather dominated blanket bog.
Methods of allocation to intervention/control	Methods of allocation	Three moors with differences in management intensity allowing older stands on one moor.
	Intervention description	Prescribed burning – ages of stands post burn advised by landowners/managers.
	Control/comparison description	Differences in vegetation character and carabid community structure in 4 Calluna life cycle classes. Life cycle classes used to represent stand age post burning.
	Sample sizes	42 sites - 15 pioneer, 11 building, 4 mature, 12 degenerate
	Baseline comparisons	None – no unburned sites sampled, though some sample plots known not to have been burned for 40+ years.
	Study sufficiently powered	Sampling not random and with confounding variables.
Outcomes and methods of analysis (inc effect size, CIs for each outcome and significance)	Primary outcome measures	Vegetation richness and abundance Invertebrate richness and abundance, carabid communities
	Secondary outcome measures	none
	Follow-up periods	n/a
	Methods of analysis	Non-parametric statistics, DECORANA.
Results		Cover of heather increased to a maximum in the mature phase then declined. There was a negative correlation between grass abundance and heather cover. Bilberry occurred in young stands but was generally absent from mature and degenerate stands and cross-leaved heath occurred only where there were gaps in the heather canopy –in

		pioneer and degenerate phases. 2507 invertebrates were taken including 398 carabids of 25 species. Other taxa collected in numbers were Arachnids, Opiliones, Collembola, Acari, ants and hemiptera. Catch per unit effort was calculated to elucidate differences in invertebrate assemblages between heather growth phases. Overall species richness did not vary between phases. Among non-coleopterans only Opiliones showed a difference in abundance being most numerous in the building phase. Diversity of carabids was highest in pioneer stands and at a minimum in mature stands. Diversity of showed no consistent correlation with environmental variables, with significant correlations with moss cover on one moor, with structural complexity of vegetation on another and no correlation with any variable on the third. Species assemblages varied with pioneer phase stands characterised by a group of species that are regarded as mobile and typically found widely in open habitats. These species are replaced as the heather growth cycle progresses and there is not a return to the community of open habitats as the heather canopy degenerates.
Notes	Limitations identified by author	Difficulty in accurate ageing of heather stands. Confounding variables such as differences in aspect, altitude and soil type.
	Limitations identified by review team	Confounding variables as above. Potential effects of fire characteristics. Lack of multivariate analysis.
	Evidence gaps and/or recommendations for further research	Multivariate analysis. Experimental manipulation including variation in fire characteristics.

	Sources of funding	Student project (Leeds University).

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	Taylor, K. & Marks, T.C.
	Year	1971
	Aim of study	To investigate the effect of burning and 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	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
	Intervention description	10yr burn rotation - 2nd burn in 1965 Grazing – present
	Control/comparison description	20yr burn rotation No grazing
	Sample sizes	2 burn treatments x 2 grazing treatments x 10 samples = 40 per sampling occasion
	Baseline comparisons	20yr rotation burn with no grazing = 10 samples per occasion
	Study sufficiently powered	Authors refer to use of initial study to define minimum sample sizes required to generate treatment differences @p=0.05
Outcomes and methods of analysis (inc effect size, CIs for each outcome and significance)	Primary outcome measures	No. of shoots/m^2 No. of ♂ & ♀ flowers Dry weight of each of leaf lamina, stems+petioles, flowers, fruits, rhizomes & roots Total N, Ca, Mg & K of aerial dry matter, rhizome & root (data for separate aerial organs not presented here).
	Secondary outcome measures	Total aerial dry weight/m^2 – data for separate organs not presented here Shoot dry weight

		Total no. of fruits and flowers per plot Ratio of rhizome dry weight:root dry weight Rhizome and root weight scaled to m^2 (based on shoot:root/rhizome= ca. 1.0)
	Follow-up periods	Identical for all plots: May-August 1969
	Methods of analysis	Standard error of means used as comparator on graphs of seasonal trend. No ANOVA presented No statistical analysis for single-sample values for rhizomes, roots, flowers & fruits
Results		**Trends with precision as differences in standard error of mean (i.e. p=0.05)**. Shoot density and total aerial dry matter is lower in the 20yr burn compared to the 10yr burn. Sheep grazing reduces total shoot density and total aerial dry matter. Shoot density tend to drop between mid-July & August in grazed plots: un-grazed stands show continued shoot proliferation through the sampling period. Individual shoot weight does not differ between 10 & 20yr burns subject to grazing and is only different in August for ungrazed plots. Trends in total aerial dry matter are highly significant ($p<0.05$). There were no differences among treatments in the concentrations in aerial dry matter of total N, P, K, Ca & Mg. Total N, P & K declined during the growing season; total Ca & Mg increased. **Trends with no statistical precision**: Grazed plants have fewer flowers and fruits

		Ungrazed plants achieve a higher rhizome weight and proportionately more root by August
Notes	Limitations identified by author	Grazing pressure from sheep is low: inappropriate to extrapolate to other sites with different stocking rates and proportions of vegetation types.
	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. Single sample for rhizome/root data leads to low explanatory power. Chemical analysis does not discriminate among plant organs – this is presented in a separate paper
	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

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) 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	Tharme, A.P., Green, R.E., Baines, D., Bainbridge, I.P, and O'Brien, M.
	Year	2001
	Aim of study	To examine the effects of habitat differences and grouse moor management on bird densities in the heather dominated uplands of England and Scotland.
	Study design	Correlation
	Quality score	2+
	External validity	EV+
Moorland suitable for red grouse	Moorland suitable for red grouse	Moorland suitable for red grouse
All moorland suitable for red grouse and within the PDNP	All moorland suitable for red grouse and within the PDNP	All moorland suitable for red grouse and within the PDNP

All moorland areas for which bird density data are available for both census years 1990 and 2004	All moorland areas for which bird density data are available for both census years 1990 and 2004	All moorland areas for which bird density data are available for both census years 1990 and 2004
Population and setting	Source population	Upland heather moorland suitable for red grouse
	Eligible population	Heather dominated uplands of England and Scotland suitable for red grouse
	Inclusion and exclusion criteria	Moorland dominated by heather (heather covered >75% of area).
	Setting	Central and Eastern highlands of Scotland, North Pennines and North York Moors, of England.
Methods of allocation to intervention/control	Methods of allocation	N/A
	Intervention description	Estates categorised as having grouse moors if at least one gamekeeper working full-time on moorland management.
	Control/comparison description	Moors managed for shooting of driven red grouse compared with those where grouse shooting absent or at low intensity.
	Sample sizes	320 1-km sample squares on 122 estates.
	Baseline comparisons	N/A Correlational study
	Study sufficiently powered	Yes
Outcomes and methods of analysis (inc effect	Primary outcome measures	Total count of a particular bird species in all the squares on an estate

size, CIs for each outcome and significance)		Number of a bird species in a 1-km square (bird density)
	Secondary outcome measures	
	Follow-up periods	N/A
	Methods of analysis	GLIM/parsimonious multiple regression models
Results		**Differences in bird density between grouse moors and other moors:** Red grouse, golden plover, curlew and lapwing occurred at significantly higher density, and meadow pipit, skylark, whinchat and crow at significantly lower density, on grouse moors than on other moors. There was no significant difference in density for black grouse, common snipe, and wheatear. BUT the differences in density between moorland types remained significant ($p<0.001$) only for golden plover and crow when variation among regions was controlled for. There was evidence of a positive effect of heather burning on the density of red grouse and golden plover and a negative effect on meadow pipit. **Habitat differences between grouse moors and other moors:** Generally the selection of heather – dominated squares resulted in the grouse moors having similar vegetation to other moors. However, grouse moors had less grass/bracken, long vegetation and more flush/grass, medium height heath, long height heath, and were less likely to be on cryptopodzol soils than other moors (all $P<0.05$ or less). NOT CLEAR WHETHER THIS CAUSE OR EFFECT On average **32% of the 1-km square on grouse moors was on peat** (compared to 22% on other other moors). **Burning**: Rotational burning of ground vegetation covered a 34% larger area on grouse moors than on other moors. Positive effect of heather burning on the density of red grouse ($p<0.001$) and golden plover ($p<0.05$) and a negative effect on meadow pipit

		recorded ($p<0.05$). Red grouse densities were increased most where burns had been carried out >1 year ago and there was moderate to good regeneration. Golden plover densities were increased across all three burn types (see below). Meadow pipit densities were significantly decreased only where burns had been carried out >1 year ago and little or no regeneration had taken place. NB These effects are deduced from Table 5, the interpretation of which is unclear. No significant evidence of burning on the remaining species (black grouse, curlew, lapwing, snipe, skylark, wheatear, whinchat, crow). NB: Other results unrelated to burning not detailed
Notes	Limitations identified by author	In relation to the burning issue, study did not discriminate between whether burning had the objective of creating a mosaic of small patches of different aged heather, or to improve the grazing of sheep. High risk of type 2 errors – when a difference in bird density that is really caused by burning is erroneously cancelled out by spurious associations with habitat variables that differ between grouse moors and other moors. Also risk of type 1 errors – if significant differences in bird density were still found after adjustment for effects of habitat and region but these were actually caused by some habitat variable that was not measured.
	Limitations identified by review team	Because the study is correlative, it struggles to distinguish the effects of rotational muirburn from those of factors such as habitat, topography, etc. No account taken of grazing – the study appears to assume that grazing levels are equal for grouse moors and other moors. Lack of information regarding the size/nature of the burns carried out.
	Evidence gaps and/or recommendations for	Requires experimental manipulation of moor burning to confirm findings as so many explanatory variables that effects are rather unclear.

	further research	
	Sources of funding	?

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	Usher, M.B.
	Year	1992
	Aim of study	To explore the diversity of the invertebrate fauna of upland communities dominated by Calluna. Subaim: to examine whether invertebrate assemblages are affected by burning and cutting of heather.
	Study design	Case-control study?
	Quality score	2-
	External validity	EV-
Population and setting	Source population	North Yorkshire Moors upland moorland
	Eligible population	Study sites were selected on 3 grouse moors in a range of habitats, including dry *Calluna* heath, wetter heathlands with rushes and *Sphagnum*, and areas with grasses

		and sedges.
	Inclusion and exclusion criteria	Areas dominated by bracken excluded
	Setting	3 grouse moors (Danby Low Moor, Danby High Moor and Kildale Moor)
Methods of allocation to intervention/control	Methods of allocation	No rationale or method provided for selecting locations of plots. Only information provided is that study sites were selected in a range of habitats, including dry *Calluna* heath, wetter heathlands with rushes and *Sphagnum*, and areas with grasses and sedges.
	Intervention description	54 sites of which 25 described as 'in heather', 17 'burnt' and 12 'cut'. No other information provided.
	Control/comparison description	Control sites were the 25' in heather' sites. Community assemblages of ground beetles and spiders compared between control and intervention sites.
	Sample sizes	54 sites of which 25 described as 'in heather', 17 'burnt' and 12 'cut'. No other information provided. 8 pitfall traps and 4 water traps/site together with suction sampling (c. once every 4 weeks).
	Baseline comparisons	N/A
	Study sufficiently powered	No power analysis. Ordination and TWINSPAN analysis used to determine whether burning was linked to a change in species assemblage of ground beetles and spiders. Poor description of methodology and analytical approach undermines the value of the paper.
Outcomes and methods	Primary outcome	Composition of species assemblage of ground beetles and spiders.

of analysis (inc effect size, CIs for each outcome and significance)	measures	
	Secondary outcome measures	Abundance of ground-dwelling beetles and spiders.
	Follow-up periods	N/A
	Methods of analysis	Ordination and TWINSPAN analysis
Results		Invertebrate diversity (spider and ground beetles) is high on upland moors (compared with low vascular plant diversity). However higher altitude heathland (at 410m) tended to be less species-rich than lower heathland (at c. 260m). The species assemblages of spider and ground beetle communities of burnt and cut moorland sites tend to differ from uncut/burnt sites (but since the management of control 'heather' sites is not detailed the exact comparison is not clear). Species assemblages vary according to the growth-phase of the heather. Some of nationally rarer species are associated with open conditions of recently cut or burnt heathland.
Notes	Limitations identified by author	Study couldn't determine at what stage in the cycle of growth-phases of heather the various 'early successional' species drop out of the spider/beetle assemblages and those more typical of mature growth stands colonise. (The apparent difference in number of spider species between high and low altitude sites may be an artefact of sample size.) Not burning related- take out?
	Limitations identified by review team	Not clear from results the extent to which effect of burning can be separated from indirect effect of changes in growth-phase of heather.

		Confounding effects of grazing and habitat type not clarified. Growth phase of heather and management history of control plots not detailed and therefore not clear whether they may have been burnt in past. If they do not support old, degenerate phase heather, they may not support the full range of species naturally occurring in completely unmanaged areas. No evaluation of time since burning on community assemblage. No evaluation of effect of burn scale on community assemblage. While concluding that the mosaic of heather growth-phases resulting from burning/cutting appears to be responsible for maintaining a diversity of faunal habitats and hence in maintaining the large number of arthropod species found in the upland heathlands, study does not mention the possibility that some species may only occur in degenerate phase heather, ie while burning may increase overall arthropod diversity, it could cause the extinction of arthropods typical of old, degenerate heather.
	Evidence gaps and/or recommendations for further research	Assuming burnt sites had been recently burnt and were therefore very open, follow up studies to assess how spider/beetle communities change as heather grew back.
	Sources of funding	BBSRC

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 upland peatlands on carbon sequestration and storage, either directly or indirectly through changes in vegetation composition and structure?

Study details	Authors	Ward, SE, Bardgett, RD, McNamara, NP, Adamson, JK & Ostle, NJ
	Year	2007
	Aim of study	To provide a greater understanding of how long-term grazing and burning control carbon dynamics in carbon rich ecosystems.
	Study design	Experiment – partially randomised controlled trial (Hard Hill expt.)
	Quality score	1++
	External validity	EV+
Population and setting	Source population	Moor House National Nature Reserve.
	Eligible population	Hard Hill experimental plots
	Inclusion and exclusion criteria	Utilised factorial experimental plots subject to a range of grazing and burning treatments since 1954.
	Setting	Upland blanket bog in a North Pennines NNR. Vegetation type M19b.

Methods of allocation to intervention/control	Methods of allocation	Factorial experiment design laid out in 1954.
	Intervention description	This experiment utilised 10yr burn and unburned (since 1954) for both grazed and ungrazed (since 1954) to give a 2 x 2 factorial design.
	Control/comparison description	No burning since 1954, no grazing since 1954, no burning or grazing since 1954.
	Sample sizes	4 repetitions in each treatment (n=16).
	Baseline comparisons	n/a – no data about pre 1954 conditions (but reference to source paper).
	Study sufficiently powered	Randomised sampling design within existing experiment structure for most parameters. Data subject to multivariate analysis and *p*-values given.
Outcomes and methods of analysis (inc effect size, CIs for each outcome and significance)	Primary outcome measures	Vegetation community composition in three categories (graminoid, ericoid, and mosses). Carbon stocks in organic (O') horizon, F and H horizons (including living roots and mychorrhiza) and litter (dead plant material on the surface and standing dead matter). Peat microbial properties and N availability. Trace gas flux (CO^2 and CH^4). Soil solution DOC.
	Secondary outcome measures	None.
	Follow-up periods	n/a
	Methods of analysis	ANOVA.

Results		Both burning and grazing reduced above ground carbon stocks and that burning reduced carbon stocks in the surface peat. No differences were found in the O’ horizon and neither grazing nor burning affected the total ecosystem C storage when sampled to 1m depth. Both burning and grazing affected vegetation composition by reducing ericoid subshrubs and bryophytes and increasing graminoids compared to unburned and ungrazed controls. The effect was especially pronounced in burned treatments where burning increased the biomass of graminoids by 88% and reduced that of shrubs and bryophytes by 51% compared to unburned controls. Soil microbial properties were unaffected by grazing and showed only minor responses to burning. There was a significant increase in biomass C:N ratio in spring and summer in burned plots. Increases in CO^2 flux of respiration and photosynthesis were found in burned and grazed treatments with the largest effect in burned treatment where the increase in CO^2 flux was over 40%. Increases in CO^2 flux were greatest in summer suggesting an interaction between land use and climate on C cycling. Burning reduced CH^4 fluxes (mean reduction 12%) relative to unburned plots. Grazing increased CH^4 fluxes (115% relative to ungrazed plots). However there was an interaction between burning and grazing such that the lowest CH4 fluxes were on the ungrazed, no burn plots. CH4 flux varies seasonally and is correlated with soil temperature. Long term management of peatlands has marked effects on C dynamics and CO^2 flux mainly related to changes in vegetation community structure.
Notes	Limitations identified by author	None.
	Limitations identified by	Study looked only at 10 yr burn vs no burn – missed the opportunity to look at 20 yr

	review team	burn plots. Results would be affected by the slow recovery of dwarf shrub vegetation at this site. Grazing rates considered are low. Burn plots were in the same stage of the burn cycle so differences between plots at different stages of recovery from burning not considered.
	Evidence gaps and/or recommendations for further research	Application to sites under a wider range of grazing management treatment. Application to sample plots at in a range of post burn ages. Expansion of study to sites with a range of climatic conditions to inform possible effects of climate change.
	Sources of funding	NERC Studentship.

Evidence Table

Name of Evidence Review:	UER
Name of Review Sub-topic (if any):	Burning
Review Question	d)

Study Details	Population and setting	Methods of allocation to intervention / control	Outcomes and methods of analysis (inc effect size, CIs for each outcome and significance	Results	Notes
Authors: Year: Aim of study: Study design: Quality Score External validity:	Source population: Eligible Population: Inclusion & exclusion criteria: Setting:	Methods of allocation: Intervention description: Control / comparison description: Sample sizes: Baseline comparisons: Study sufficiently powered	Primary outcome measures: Secondary outcome measures: Follow-up periods: Methods of analysis:		Limitations identified by author: Limitations identified by review team: Evidence gaps and/pr recommendations for further research: Sources of funding:
Worral et al. (2007) The effects of burning and	Source population: Blanket peat (some eroded	Methods of allocation: Experiment employs a multi factorial block design, with treatments partly randomly	Primary outcomes measures: Depth to water table	Significant differences were found for solid depth to water between different	Only two of the four possible blocks were used due to restricted resources meaning that

sheep grazing on water table depth and soil water quality in upland peat. NB: evaluated with related Durham Univ. hydrology/soil water and chemistry studies in the Hard Hill expt 2005-08. Aim of study: To understand the effects of different rotational burning cycles and grazing intensities on hydrology and water quality of an upland peat.	due to gripping). Vegetation dominated by Eriophorum sp (cotton grass), C.vulgaris (heather) and Sphagnum sp. Setting: Trout Beck catchment in the headwater of the River Tees within Moor House NNR.	assigned. Two blocks of heather moorland were selected and each was sub divided into 6 plots ; three plots were enclosed to prevent grazing and three were left unfenced to allow grazing (grazed and ungrazed) Within each group of 3 plots, a plot was randomly assigned to each of 3 burning treatments, none since 1954, 10 yearly and 20 yearly) Control: Unburnt and grazed treatments were treated as the control when depth to water table measurements required normalisation. Sample sizes: Three dipwell measurements per plot (unclear if these were randomly positioned)	measured and Soil water from dipwells was subject to water analyses for pH, conductivity, absorbance at 400nm and DOC concentration. Samples were taken at 16 fortnightly intervals between 6th April and 28th September. Analysis was undertaken on raw and normalised data, to minimize effect of differences in sampling days (caused by delayed introduction of dipwell on 10 year burn sites). ANOVAs and ANCOVAs conducted with depth of water table used as a covariate in analysis of soild water pH, conductivity, absorbance, DOC and specific absorbance.	burning rotations and grazing intensities. Depth to water table was greatest on plots where burning did not occur or for longer burning cycles where livestock had been excluded. Whilst not evaluated as part of this experiment these differences are most likely due to differences in the overlying vegetation, in particular dwarf shrub development on ungrazed/infrequently burnt plots leading to increased evapo - transpiration. The pH and conductivity of sampled soil water	all management combinations were examined in duplicate and not four times. Sampling of soil water initially included only no burning and 20 year rotation plots and not 10 year rotations. On assessment of initial results 10 year plots were sampled 2 months later, so have an incomplete data set. Lack of replication and loss of orthogonality means this experiment is insufficiently powered despite the data being normalised. The authors acknowledge this. A power calculation was undertaken and probability of a Type II error, finding no sig difference when one

Study design: Randomised Control Trial for burning treatments but Non randomised control trial for grazing treatments Quality score: 1+ [overall for related Hard Hill studies.] External validity: EV+			Tukey test was used for pairwise comparisons between factor levels to test for significance, at 95% probability. Levene test was used to assess homogeneity of variance with respect to burning, grazing and day.	showed no significant difference between grazing treatments, with the presence of burning being the most important factor (frequency of the burning cycle was not important). Burning decreases the pH of the soil water by an average of 14%. The DOC content showed no significant difference between grazing treatments but showed a significant decrease with the presence of burning, though no direct relationship with the depth to water table could be found.	does exist was found to be likely in some instances. Also an important confounding variable has not been accounted (e.g. existing vegetation structure/composition). Whilst this is not explicitly recognised it is acknowledged that significant differences in water table depth correspond to the development of shrubby vegetation and vegetation composition per se. This variable is likely to have had both a direct (soil water depth) and indirect effect (influencing extent and intensity of grazing).

				For water quality parameters it is not the frequency of burning but the presence of burning that makes the sig diff. It is important to note that this study was undertaken at the end of a burn cycle and conditions and results may be very different shortly after a burn.	

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	Worrall, F. & Warburton, J. Assessing successful strategies for grip-blocking in the North Pennines AONB. Rep. to North Pennines AONB Partnership.
	Year	2009
	Aim of study	To identify which grips carry the most flow, water colour and are most eroded, which grip blocks most reduce these and what proportion of blocks fail, what factors cause failure, how quickly do grip 'heal' after blocking and which blocking techniques are most effective. Included evidence of burning (though not explained whether related to across or adjacent to grip) as an explanatory variable.
	Study design	Correlation study.
	Quality score	2+
	External validity	EV+
Population and setting	Source population	N Pennines AONB blanket bog.
	Eligible population	Five 'sites' in N Pennines AONB (sampled with total c.600 grip 'sections').
	Inclusion and exclusion	NR

	criteria	
	Setting	Five North Pennine blanket bog sites
Methods of allocation to intervention/control	Methods of allocation	NR
	Intervention description	Blocking of grip using various techniques.
	Control/comparison description	Unblocked grips.
	Sample sizes	599 'sections' (403 blocked and 197 'open') of grips (not described, eg length) from 5 sites, range 51-270/site.
	Baseline comparisons	None, as a single survey after blocking. Unblocked sections act as a control (albeit not for same sections and not evenly distributed across sites or even present at all at some sites).
	Study sufficiently powered	No power analysis. Relatively large sample sizes across sites, but variable per site and fewer for unblocked sections.
Outcomes and methods of analysis (inc effect size, CIs for each outcome and significance)	Primary outcome measures	Block type, blocking success, antecendent hydrological conditions, flow and water quality including colour.
	Secondary outcome measures	Location (incl. position in drainage network, local slope, cross-slope, grip-spacing, dominanat vegetation type, grip dimensions, local depth of peat/erosion and burning.
	Follow-up periods	Time after grip digging unknown and time after blocking known but not reported. Assumed that surveys likely to be relatively soon after blocking.
	Methods of analysis	Multiple linear regression for continuous variables, ANOVA (influence of binary variables on continuous variables), logistic regression (continuous variables on binary

		variables) and frequency analysis with chi-square testing (Binary on binary).
Results		"Blocking caused a significant decrease in water colour but this was greatest when blocking occurred in areas of managed burning." "... water colour in grip sections was highest where there was evidence of burning and evidence of heather though this would seem contradictory as burning is used to control heather" [though the last comment is debatable as it is carried out to maintain heather in pioneer/building phases and is often the main or only easily burned vegetation on blanket bogs].
Notes	Limitations identified by author	Low sample size in relation to occurrence of some variables/combinations and 'cross-classification' in relation to differences between numbers of blocked and (fewer) unblocked sections overall and especially between sites, with none blocked or unblocked on some sites (reflecting fact that most grips are blocked when it is carried out). Also time since grips dug unknown.
	Limitations identified by review team	No information given on site selection or sampling of grips and sections within sites nor explanation of different sample sizes per site. Linked to this, no descriptive information given about the sites other than site names. Potential contamination and confounding factors NR.
	Evidence gaps and/or recommendations for further research	Collect data on time since grips dug for samples. Sample sites with both blocked and unblocked grips (Cronkley Scar [or perhaps additional sites]).
	Sources of funding	N Pennines AONB Partnership.

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 & d

Study details	Authors	Worrall, Bell & Bhogal
	Year	2010a
	Aim of study	To propose a method for assessing the probability that land management interventions will lead to an improvement in the carbon sink represented by peat soils.
	Study design	2: quantitative observational
	Quality score	2+
	External validity	EV+
Population and setting	Source population	Deep peats >40cm, specific vegetation communities not described. The study was not limited to the uplands – it included raised bog as well as blanket bog and mires, but not fens.
	Eligible population	N/A
	Inclusion and exclusion criteria	Studies considering carbon budget were used in the research, there was no critical assessment of research quality

	Setting	Data from UK, Europe and N. America included. Data from Tundra/Arctic was excluded
Methods of allocation to intervention/control	Methods of allocation	N/A
	Intervention description	N/A
	Control/comparison description	N/A
	Sample sizes	N/R
	Baseline comparisons	N/A
	Study sufficiently powered	N/A
Outcomes and methods of analysis (inc effect size, CIs for each outcome and significance)	Primary outcome measures	Probability of managed burning leading to an improvement in the carbon sink represented by peat soils
	Secondary outcome measures	N/A
	Follow-up periods	N/A
	Methods of analysis	Meta-analysis based on a review of the literature
Results		A 7% probability of managed burning improving the carbon budget (and a 40% probability of a GHG benefit) was calculated. There were no studies included of cessation of burning, but the study assumes the opposite of burning, ie a 93% chance of carbon budget benefit from cessation of managed burning.
Notes	Limitations identified by	The number of studies considering the whole carbon budget is limited, therefore,

	author	studies that considered individual components had to be relied upon. The study did not filter/assess reviewed papers for quality due to lack of primary studies The approach does not attempt to measure size of effect The sample size was insufficient to reach the approximation of normality and therefore the capacity to test between management interventions is limited
	Limitations identified by review team	-
	Evidence gaps and/or recommendations for further research	Inclusion of effect size Meta-analysis by narrower (e.g. UK uplands) habitat (currently unfeasible due to lack of studies)
	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)	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 food risk), either directly or indirectly through changes in vegetation composition and structure?

Study details	Authors	Worrall, F, Rowson, J & Dixon, S
	Year	2012
	Aim of study	To compare the impact of managed burning over time with heather cutting to contrast their effects on peatland hydrology and carbon storage.
	Study design	2: site comparison/correlation
	Quality score	2-
	External validity	EV-
Population and setting	Source population	Moorland in the Peak District, Pennines
	Eligible population	Heath vegetation on deep peat soils.
	Inclusion and exclusion criteria	Not explained.

	Setting	Goyt Valley, Peak District National Park, Derbyshire.
Methods of allocation to intervention/control	Methods of allocation	Experimental sites chosen to avoid drainage effects between them .
	Intervention description	Fresh burn I yr old burn 5 yr old burn Fresh cut and remove litter Fresh cut and leave litter 1 yr old cut and remove litter 1 yr old cut and leave litter
	Control/comparison description	Unburned and uncut (mature to degenerate Calluna)
	Sample sizes	Plots duplicated within each treatment and samples for soil water and runoff replicated x3 In total there were 63 dipwells and 63 runoff traps x sampled a maximum of 773 times across the study – low water levels resulted in some missing observations.
	Baseline comparisons	In unburned / uncut control.
	Study sufficiently powered	No - Lack of explanation in ANOVA means that factors not considered could be significant.
Outcomes and methods of analysis (inc effect	Primary outcome measures	Depth to water table in dipwells Soil water in dipwells and runoff analysed for pH, conductivity, absorbance 400nm,

size, CIs for each outcome and significance)		E4/E6 (ratio of absorbance at 465nm to 665nm) and DOC concentration.
	Secondary outcome measures	n/a
	Follow-up periods	May 2008 – June 2009
	Methods of analysis	ANOVA
Results		Depth to water table was significantly different in all treatments except new burn. When data were combined to leave three treatments (control, cut and burnt) there were significant differences between both burn and cut treatments from control. This can be explained by a loss of vegetation which reduces evapotranspiration. There are significant differences between cut and burned treatments with lower water tables in cut treatments. DOC concentrations in the cut and leave treatment were significantly different from controls other treatments were not. When treatments were combined only 5% of the variation is explained by treatment. No significant differences were found in surface run-off between treatments. Differences between soil water and surface water were independent of treatment. The study concludes that t there is a significant effect of cutting and burning on soil but not surface runoff DOC. Treatment appeared to decrease DOC possibly driven by treatment reducing depth to water table. This may result in dilution of soil water by surface water or rain water which is low in DOC. These studies were conducted on dry peat (average water table depth 42cm) and in sites where water tables are normally closer to the surface may see little effect. It is not possible in this study to show that changes in soil DOC result in similar changes to DOC in catchment stream runoff.
Notes	Limitations identified by author	Not full factorial design. None of the ANOVA conducted fully explains all variance. Error terms in DOC analysis is

		the most important term. Lack of explanation means that factors not considered could be significant.
	Limitations identified by review team	Study site is heath on deep peat not blanket bog. Cut sites investigated only 1 year old – not possible to say how long effects last.
	Evidence gaps and/or recommendations for further research	Study site is heath on deep peat not blanket bog. Study cannot assess whether flowpaths are affected by hydraulic conductivity and macroporosity as well as evapotranspiration from the soil.
	Sources of funding	Not reported.

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 food risk), either directly or indirectly through changes in vegetation composition and structure?

Study details	Authors	A.R. Yallop & B. Clutterbuck
	Year	2009
	Aim of study	This study investigates the extent to which common land use and management practices undertaken in England may affect DOC concentration in waters draining upland peat catchments.
	Study design	2: catchment-scale correlation study
	Quality score	2++
	External validity	EV+
Population and setting	Source population	Moorland in N England
	Eligible population	Four discrete upland areas of England – sites in north, south and central parts of the southern Pennine chain and the North Yorkshire Moors
	Inclusion and exclusion criteria	Study reports from small areas of moorland (013 – 3km2 and larger catchments (1.5-21km2 Larger scale analysis 8 catchments where colour parameters are measured at

		Water Treatment Works. Only sites where sources of water could be determined were selected. Catchments with less than 85% blanket peat were excluded from analysis.
	Setting	Upland blanket bog.
Methods of allocation to intervention/control	Methods of allocation	An initial set of 150 catchments (typically smaller than 3 km2) were defined by selecting high-order drainage channels in upland habitats as defined as upland heathland and bog. Those less than a minimum area of 25% organic soil groups were excluded. A subset that clustered within 20 km of each other at the four study areas was selected to minimise effects arising from local meteorological or acid depositional differences. This yielded a total of 50 catchments.
	Intervention description	n/a
	Control/comparison description	Multivariate analysis correlates catchment variables with DOC concentrations.
	Sample sizes	50 catchments sampled – outflows sampled x 4.
	Baseline comparisons	None.
	Study sufficiently powered	New and recent burning on blanket peat explained 77% of variance in DOC concentration
Outcomes and methods of analysis (inc effect size, CIs for each outcome and significance)	Primary outcome measures	Dissolved Organic Carbon concentration in upland drainage waters
	Secondary outcome measures	None.
	Follow-up periods	All samples collected in 2005 in 4 sample periods each of 5 days in January, March,

		November and December.
	Methods of analysis	Stepwise multiple-regression
Results		The proportion of the catchment as blanket bog is highly correlated to DOC ($p<0.001$). The most significant predictor of DOC was the proportion of new burn. The degree of variance explained increased when recent burning was added to the regression. In the four sample areas proportion of new burn on blanket bog was the most significant variable affecting DOC in the three Pennine areas but no relationships between catchment variables and DOC were found in the North York Moors sample area. No significant relationships were found between rainfall prior to sampling and DOC. For the 8 catchments new burning explains 64% of the variance in DOC concentration between catchments.
Notes	Limitations identified by author	Some data are missing because of access problems.
	Limitations identified by review team	DOC samples collected in winter but increases in surface temperature through removal of vegetation are invoked as a factor in causing increases in DOC in new burn areas. Sampling in summer may have allowed more confidence to be attached to this assertion.
	Evidence gaps and/or recommendations for further research	Evidence for the cause of variation in DOC. Further research to explain the contrary evidence for an effect of burning on DOC in this study and for a lack of effect in other studies. E.g. study that measures interstitial DOC and DOC in catchment drainage water.
	Sources of funding	Yorkshire Water Services Limited

Yallop and Clutterbuck (2009) examined the effect of land use and management on Dissolved Organic Carbon production at two scales – within 50 discrete catchments <3km2 and at a larger scale in 8 catchments where water colour data from water treatment works are available. Sites were in the South, West and North Yorkshire Pennines and on the North York Moors.

Catchments were characterised into three types according to soils, (blanket peat, peaty topsoils and non-peaty soils), vegetation character and presence of drains. Fire management was assessed from air photographs and extent of burns measured in 4 classes (new -<approx 4 years old, , recent -4 -8 years approx, and two classes of older burns – 8-20 years and older). DOC was measured in outflow streams for the small catchments and from hazen colour data from water treatment works from the larger catchments

The proportion of the catchment as blanket bog is highly correlated to DOC ($p<0.001$). The most significant predictor of DOC was the proportion of new burn. The degree of variance explained increased when recent burning was added to the regression. The proportion of new burn on blanket bog was the most significant variable affecting DOC in the three Pennine areas but no relationships between catchment variables and DOC were found in the North York Moors sample area. No significant relationships were found between rainfall prior to sampling and DOC. For the 8 larger catchments new burning explains 64% of the variance in DOC concentration between catchments.

The results are interpreted to suggest that the management of vegetation on peat soils by burning is of relevance to water utilities as it affects water quality. The recent upward trend of colour in water may be due to recent changes in management. The lack of relationship between burning and DOC in other soil types (e.g. at the North York Moors study area), suggests that it is not burning *per se* that affects DOC release but burning on deep peat soils.

A suggested causal mechanism for the effect of burning on DOC release is through an increase in humic substances from peat decomposition. The changes in the hydrological and microbiological environment caused by exposure of the peat surface by burning could lead to increased decomposition. The mean surface area of exposed peat in new burns in this study is 84%. Bare peat is then exposed to increased solar radiation. Removal of the canopy also increases infiltration and through flow and this may also contribute to drying of the soil profile also resulting in an increase in microbial activity.

Other studies have found no link between burning and increased DOC production. Other studies (Ward 2007 and Worrall 2007) relate to burns that had already recovered to full canopy and correspond to stands examined in this study where no effect of DOC was found either. Also, in those studies DOC was examined in interstitial water not in stream run-off where the relationships between burning and DOC may be different

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)	h) What are the **extent**, **frequency**, practice and type of managed burning (including 'cool burning') on upland peatlands (including in relation to designated sites and water catchments)?

Study details	Authors	Yallop et al. 2006b [NB: ENRR 667 also refers to the same work and is also included in this assessment.]
	Year	2005/2006b
	Aim of study	To survey the national scale of fire managemnet and use historical photography to identify medium-term trends in its use
	Study design	Quantitative observational/correlation (sample survey/monitoring)
	Quality score	2+
	External validity	EV+
Population and setting	Source population	CS2000 Upland Environment Zone in England
	Eligible population	All area within zone eligible for inclusion in sample 1Km squares
	Inclusion and exclusion criteria	Systematic design to given even coverage

	Setting	Across English uplands
Methods of allocation to intervention/control	Methods of allocation	2% sample of 1 km squares (208) using random systematic design to give even coverage (with 2 samples per 10 km x 10 km 'block'). For change part of study, only original sample squares within National Parks used (only 23). In assessing photos moorland divided into just 2 recognisable types: "dwarf shrub heath" (including DS on bog etc) and graminoid-dominated.
	Intervention description	n/a
	Control/comparison description	n/a
	Sample sizes	2% (208 1 km sqs) and NP subsample (28)
	Baseline comparisons	1970s aerial photograghs
	Study sufficiently powered	n/a
Outcomes and methods of analysis (inc effect size, CIs for each outcome and significance)	Primary outcome measures	Area burned by age class. Aerial photograph examined to identify areas of vegetation that had been burnt and to then classify them to an age class. Where possible burn age was ground truthed or possible age refined using quadrat field data or from a known heather height/age relationship.
	Secondary outcome measures	Estimations of repeat time where made using simple equasion $R = {}^{D1+D2/C1+C2}$ based on Class's 1 and 2 alone
	Follow-up periods	n/a
	Methods of analysis	Baisc summary stats presented in main anaylsis of proportions burnt by age class and repeat times. For the change sub sample, paired t test and Wilcoxon signed rank test

		were used.
Results		Identified four classes of regrowth related to burning from aerial imagery. Visible evidence of burning was found consistently on dwarf shrub heath and bog.(71% of sample area) of which 17% by area had been burned in previous 4 years, equivalent to 114 km^2/yr. [Though not referred to, given the areas covered by heath and bog nationally, it is likely that a significant proportion, perhaps over half, of this is on deep peat.] In 51% of sample sites containing DSH/Calluna present it was possible to estimate a repeat time. Estimated repeat times lay between 14-25 years, median c.20 years. Within most of the NP subsample there had been a significant increase in the extent of new burns (from 15.1% to 29.7%) between the 1970s and 2000.
Notes	Limitations identified by author	Quality of, and difficulties in assessing, AP. No burning identified on grass/sedge-dominated moorland, though sample groundd data from Exmoor identified small extent burned. Suggests more difficult to ID from API due to transient nature of impact and less burnt. Difficulties in obtaining older AP to assess change (only done in NP subsample).
	Limitations identified by review team	Blanket bog/peat not separated from (but included in) wider heather/DS-dominated moorland. [Though recently addressed in new report yet to be assessed – could be incorporated with this assessment?] No mention of impact of grazing on vegetation recovery. Ground truthing limited and difficult.
	Evidence gaps and/or recommendations for	First large-scale analysis of the current burning practices in England. There is a need to extend this data set to include the extent and distribution of burning management, particularly on bogs even if they are already considered to be in a

	further research	degraded state. Such information may prove useful in determining the effects of prescribed burning on blanket bog and future condition
	Sources of funding	English Nature.

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)	h) What are the extent, frequency, practice and type of managed burning (including 'cool burning') on upland peatlands (including in relation to designated sites and water catchments)?

Study details	Authors	Yallop AR, Thacker J, & Clutterbuck B
	Year	2006a
	Aim of study	To map burning activity within the upland areas of the North Pennine AONB using a sample based approach, based on a group of aerial photographs flown between 2001-2003
	Study design	2 Correlation/observational (sample survey).
	Quality score	2+
	External validity	EV+
Population and setting	Source population	Upland areas of the North Pennine AONB.
	Eligible population	Area mapped is defined as portions of the English Nature Digital datasets ' Blanket Bog v1.2' and 'Upland Heath v 1.2' that lie within the north Pennines AONB. No real description of what these mean and there are issues of overlaps with these datasets.

	Inclusion and exclusion criteria	Whole area of selected area looked at on a 35m grid.
	Setting	Upland areas of North Pennine AONB
Methods of allocation to intervention/control	Methods of allocation	All of the datasets from English Nature Digital datasets ' Blanket Bog v1.2' and 'Upland Heath v 1.2' that lie within the north Pennines AONB. It does comment on the fact that this did include some areas of habitat that were not heather dominated. These were not excluded from study area and if grid points landed on them they were included in the non-burnt category.
	Intervention description	Visibly burnt • 1: New burn – within approx. 0–4.6 years • 2: Recent burn – within approx. 3-7 years •
	Control/comparison description	Not visibly burnt • 0: No visual presence of ericaceous shrub • 3: Visually closed canopy – estimated age 6-15 years • 4: Mature, degenerate areas of ericaceous shrub, greater than 15-25 years or unmanaged
	Sample sizes	Points on a 35m grid spacing across whole of sample area, blanket bog and upland heath in North Pennine AONB
	Baseline comparisons	N/A

	Study sufficiently powered	Looks at whole of sample area. Issues with quality of datasets, particularly overlaps between them and inclusion of non- heather habitats mentioned but not really resolved. Issues with quality of aerial photographs addressed by combining finer categories of burn class into coarser categories. No ground truthing of interpretation of burn age classes.
Outcomes and methods of analysis (inc effect size, CIs for each outcome and significance)	Primary outcome measures	Visible burn presence/absence
	Secondary outcome measures	Burn repeat times. This is not adequately explained but is assumed to be estimated on the basis of the proportion burnt compared to total area, along with range of age of burns up to 7 years
	Follow-up periods	N/A
	Methods of analysis	No statistical analysis. Simply presence/absence and counts of points. Not clear how proportions of burnt vs unburnt are derived. This is not an area figure so must be proportion of points looked at?
Results		Yallop et al recorded visible burning on a 35m grid for Blanket Bog and Upland Heath within the north Pennines AONB. This was expressed as a proportion of burnt points, but is occasionally confusing whether proportions of points or area is being discussed. The results are expressed as percentage of area and they found that 20.7% of the total was burnt with 19.2% of bog burnt and 27.5% of heath burnt. This was translated into repeat burning times and expressed as a frequency of burning for a particular area. This was compared between bog and heath and shown for all the SSSIs within the AONB.

		Half of the area of bog and about 28% of heath showed no evidence of burning. 20% of bog is claimed to be burnt with a repeat time of under 20 years. At least 30% of the bog in upland SSSIs in the AONB is under intensive burning regimes with repeat times of less than 20 years (the bog of four SSSIs, amounting to 33.6% of the area of bog in SSSIs, have repeat times this short).
Notes	Limitations identified by author	As the map datasets used include some non-heather habitat, proportions of burnt habitat may be under-estimated The interpretation assumes that burn signatures are visible in bogs for the same length of time as they are on heath. They acknowledge that we need more detailed knowledge of both the distribution of community types and the duration of visibility of burn signatures. However, they considered it unlikely the results gained by such considerations would be greatly different.
	Limitations identified by review team	• Overlap between blanket bog v1.2 and upland heath v1.2 but no attempt to explain or improve these datasets. Suggests that the ability to distinguish blanket bog and upland heath could be called into question. • No ground truthing on age range of visible burns • Visible burns on heath and bog treated the same although they acknowledge that there may be differences • Repeat times calculation is not explained in this paper or cross referenced. Questions of burn age interpretation may make these calculations invalid. • Point data appear to have been extrapolated into area figures. This is again inadequately explained, but causes some concern •
	Evidence gaps and/or recommendations for	Could possibly have looked at other factors which might influence burning patterns such as slope, aspect, altitude and distance to tracks.

	further research	Could also have looked at evidence of trees in areas which appear unmanaged (this seems to be an issue in parts of the country?) Different ages of aerial photography are available and this type of approach could be used to compare calculated repeat times with actual repeat times
	Sources of funding	EN

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	YALLOP *et al*. [Also White 2004.]
	Year	2008
	Aim of study	A pilot correlation study on the influence of management burning on water colour. Three catchments in Yorkshire that had good data from long-term water treatment works (WTW) for well-defined, unambiguous *moorland* catchments. Using aerial photographs from 2000 and 2005, they mapped the proportions of major vegetation types and burning. Four burn age classes were identified and soil types determined from the UK National Soil Resource Institute (NSRI) digital soil map. They studied 13 smaller, discrete sub-catchments within the 3 main catchments (with two-seven/main catchment). The water draining each was sampled in January 2001 with colour determined as Hazen units by the platinum-cobalt standard method using a spectrophotometer. In addition, three areas of differing vegetation type on *deep peat* were studied: new managed *Calluna* burn (<2 years old); an adjacent block of closed canopy regenerating *Calluna*; and an area of grass/sedge moor. All three sites were clustered within <10 m, therefore experiencing essentially identical hydrological and meteorological conditions. The percentage area of soil types, burn class and factorial

		combinations of these were tested as predictors for water colour sampled in watercourses draining each sub-catchment.
	Study design	2: correlation study (catchment scale) and survey of sample plots.
	Quality score	2+
	External validity	EV+
Population and setting	Source population	Blanket bog in Yorkshire.
	Eligible population	Sub-catchments within three sites (large catchments).
	Inclusion and exclusion criteria	Catchments selected based on the availability of data from long-term water treatment works (WTW) from well-defined and unambiguous catchment areas.
	Setting	Blanket bog in three sites in Yorkshire.
Methods of allocation to intervention/control	Methods of allocation	NA
	Intervention description	Managed burning
	Control/comparison description	NA, though catchments include unburned areas.
	Sample sizes	13 smaller, discrete sub-catchments within 3 main sites/catchments (with two-seven sub-catchments/main catchment).
	Baseline comparisons	NA, though change recorded from 2000 to 2005 aerial photographs.
	Study sufficiently powered	NR

Outcomes and methods of analysis (inc effect size, CIs for each outcome and significance)	Primary outcome measures	Water colouration (determined as Hazen by the platinum-cobalt standard method).
	Secondary outcome measures	Areas of soil types (including recent burns), landcover and management class in sub-catchments.
	Follow-up periods	Water colouration data from 1992–2005. The land cover and management were mapped using year 2000 and 2005 imagery.
	Methods of analysis	The percentage area of all soil types and management classes, together with factorial combinations of these, for each sub-catchment were tested as predictors for the water colour samples taken during field survey draining each sub-catchment. Values of <1% of the sample area were rounded to 0% as they are below the estimated accuracy of the aerial photograph interpretation. Combinations 3 with less than two observations were excluded, giving a total of 13 factors for analysis. These were tested against colour (Hazen) using forward entry multiple regression. Prior to analysis all proportional data were arcsin-square root transformed.
Results		There were 13 combinations of soil, landcover and management class in the sub-catchments; only one, the area of exposed peat surface from recent burn management on deep peat soils was accepted into the regression (adjusted $r^2 = 0.82$, $p < 0.0001$) showing it was the strongest predictor of water colour for the January water samples, all other factors were excluded with a strong linear relationship between increased burning and increased water colour in January. Similarly for the long term water colour monitoring, only the area of exposed peat surface from recent burn management for grouse on deep peat soils was accepted into the regression (adjusted $r^2 = 0.94$, $p < 0.0001$). There was a similarly strong linear relationship between exposed peat from burning and average water colour for both 1992-1999 and 2002-2005. In the discussion there is a description of work done on soil temperature and water table under different burning regimes/land cover. Soil temperatures under the exposed peat surface of new burn were on average 2-4 degrees warmer than the other two sites. Water tables were

		consistently high and near to the soil surface under grass/sedge moor. Both Calluna sites had considerably lower water tables. Water table oscillations were apparent under the area of new burn showing that burnt areas dry deeper in dry periods but rapidly rewet because of an absence of canopy during even short periods of rainfall. The discussion states that there is a highly significant relationship between the fraction of new management burns on deep peat and DOC release. Other research suggests that lowering of water tables and soil temperature increases have been implicated in enhanced release of carbon from the soil organic pool. Their work suggests that soil temperatures are higher and the water table oscillates under recent burns. Their results suggest that burnt areas dry deeper in dry periods but rapidly rewet because of an absence of canopy during even short periods of rainfall. Such cycles would ensure both high DOC production and rapid removal from the profile and delivery to drainage systems.
Notes	Limitations identified by author	NR
	Limitations identified by review team	Limited to just three sites (though covering thirteen sub-catchments and it was a pilot study which was followed up with larger, more geographically wider distributed samples in subsequent studies by the authors). The mechanism for the increase in colouration after recent burns is unclear.
	Evidence gaps and/or recommendations for further research	Extension of the studies to more sites which has been done since.
	Sources of funding	Yorkshire Water Ltd.

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 biodiversity) and water flow (including downstream flood risk), either directly or indirectly through changes in vegetation composition and structure?

Study details	Authors	Yallop, A., Clutterbuck, B. & Thacker, J.
	Year	2010
	Aim of study	To determine the role of temperature, declining sulphur deposition and burn management on humic DOC export in upland peat catchments.
	Study design	Correlation
	Quality score	2++
	External validity	EV+ (but see limitations)
Population and setting	Source population	Upland peatland, South Pennines
	Eligible population	Catchments with blanket peat managed for red grouse using burning
	Inclusion and exclusion criteria	Availability of long term data set for water colour/quality

	Setting	3 x adjacent reservoir catchments: Langsett, Broomhead & Agden
Methods of allocation to intervention/control	Methods of allocation	No intervention used. Changes over time in water colour data from 1975 to 2005 inclusive are used as a proxy for hDOC specifically.
	Intervention description	Temperature, acid deposition and land use changes are selected explanatory variables applicable to all 3 catchments.
	Control/comparison description	No control for the empirical study. Results are contrasted with the unburnt catchment of Moor House NNR (North Pennines) in the discussion
	Sample sizes	Monthly water colour data for each catchment from 1975 to 2005 inclusive Monthly run-off data from 1975 to 2005, derived from the validated linear relationship between rainfall & runoff estimated from 29 catchments with both data sets Monthly temperatures from 1975 to 2006 Monthly total non-marine xSO_4^{2-} from 1986 to 2005 Land use cover of 6 vegetation classes plus 4 x burn scar age/stage classes for 6 x discrete years (1976, 1989, 1995, 2001, 2003 & 2005)
	Baseline comparisons	Not included as part of statistical treatment of data, but presented for comparative purposes: mean monthly DOC 1992-2006, Moor House NNR
	Study sufficiently powered	Data set is sufficiently large and 3 catchments are pooled initially to examine overall trends, after which individual site trends are investigated (lower statistical power for these constrains intra-site comparisons).
Outcomes and methods of analysis (inc effect size, CIs for each	Primary outcome measures	hDOC concentration – calculated by converting water colour data (either Hazen or UV absorbance) mean monthly water runoff per catchment – derived from generalised regression of

outcome and significance)		rainfall v runoff for 29 catchments with appropriate data and validated using 7 predictor sites most similar to the 3 study sites
	Secondary outcome measures	Monthly hDOC efflux (hDOC concentration x mean monthly runoff) Annual fluvial carbon export per m^2 peat (sum of monthly hDOC efflux for a catchment scaled for the area of blanket peat therein) Area of burns scar age class in each year of imaging for each of the 3 catchments Background annual hDOC efflux with no controlled burning
	Follow-up periods	30yrs for land use changes & temperature 20 yrs for acid deposition
	Methods of analysis	Forward-entry step wise multiple regression Individual regression Seasonal Kendall test for trends in monthly and annual hDOC for the period 1990-2005, i.e. excluding the more contentious UV absorbance data.
Results		From 1990-2005 there is a highly significant increasing trend for estimated hDOC efflux ($p<0.001$ – 1.28-5.94 x 10^6 g yr^{-1}), and concordance between this and hDOC concentration Estimated fluvial export of hDOC was 9.4-11.8 g $m^{-2}yr^{-1}$ in 1976; 27.7-29.3 g $m^{-2}yr^{-1}$ in 2000 For pooled data, 1989-2005, proportion of new burn on burned blanket peat was most significant factor relating to hDOC efflux (r^2 = 0.39, p=0.009): this rises to R^2 = 0.58 ($p<0.001$) when 1976 data are added. Wet deposition of xSO_4^{2-} has a weaker inverse relationship from 1989-2005 (r^2=0.2,

		p=0.05). For individual catchments proportion of new burn is the only significant factor (r^2= 0.68 to 0.79 ($p<0.05$ for each) Estimated from regression, background hDOC export in this locality with no burning is 9.5 +/- 2.5 g $m^{-2}yr^{-1}$ Areas of newly burnt peat account for an efflux of hDOC of 79.6+/-22.4 g $m^{-2}yr^{-1}$
Notes	Limitations identified by author	Model or rainfall versus runoff does not account for dry antecedent conditions thus probably overestimating runoff: DOC production may also be reduced during periods of drought. Although the above may affect absolute values they do not influence the time trend observed. Lack of a relationship between xSO_4^{2-} and hDOC at individual catchment level may be because of weak analytical power or because sulphur deposition is heterogeneous i.e. trend obfuscated by a monitoring station 20km distance. Historical reconstructions can suffer from confounding variables, e.g. summer drought (such as that in 1995) may have an interactive affect with peat burning, which exposes the surface for a number of years. Lack of compositional or dating measures for hDOC means its source cannot be determined. Other sources of fluvial carbon fluxes (e.g. POC) are not accounted for but will enhance C loss.
	Limitations identified by review team	Clay et al. (2012) question the validity of using water colour as a proxy for DOC, as the two variables showed independent responses at the plot-scale within a 10yr burn chronosquence. It is not clear how these more recent data can be related to the specific

		hDOC estimated in this study and whether they invalidate the conclusions or not.
	Evidence gaps and/or recommendations for further research	Clarification of the appropriateness of various measures used to quantify DOC either directly or indirectly. Effects of grazing on the burning/DOC efflux relationship.
	Sources of funding	Yorkshire Water Services Ltd.

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)	h) burning distribution and extent

Study details	Authors	YALLOP *et al*.
	Year	2012
	Aim of study	To remap the extent of burning on *blanket bog* and *deep peat* soils nationally (using 2000 aerial photos) and in the North Pennines AONB (2001-03) based on re-examination and reconciliation of data generated in previous studies by Yallop *et al*. (2005, 2006a, b) and unpublished data held by Natural England from mapping of new moorland burning in the entirety of the Peak District NP in 2005 and the North York Moors NP in 2009 using image segmentation techniques on 4-band digital aerial imagery. Burn mapping from these studies was overlain on a peat soil dataset (National Soil Resource Institute deep and blanket peat soil series), for the first time, and the English Nature Blanket Bog (and Upland Heathland) Priority Habitat Maps, for the first time for the national dataset.
	Study design	2: aerial photographic interpretation sample/census.
	Quality score	2++
	External validity	EV++

Population and setting	Source population	Moorland blanket bog and peat in England (and also specifically in North Pennines, North York Moors and Peak District).
	Eligible population	As above.
	Inclusion and exclusion criteria	NA. National sample based on stratified random sample within upland areas.
	Setting	English blanket bog/peat.
Methods of allocation to intervention/control	Methods of allocation	NA
	Intervention description	Managed burning.
	Control/comparison description	NA, though sample includes unburnt areas.
	Sample sizes	National sample = 2%; other areas were a census within habitat/peat.
	Baseline comparisons	NA, though parts involved a reconciliation with previous studies (see above).
	Study sufficiently powered	NA
Outcomes and methods of analysis (inc effect size, CIs for each outcome and significance)	Primary outcome measures	Mapped distribution of burning, including by designated sites, deep peat and blanket bog habitat.
	Secondary outcome measures	Burning 'repeat times' (rotation lengths). Due to differences in the reported duration of burn age classes, the extent of burning was summarised as annualised rates to allow comparisons between the different areas.
	Follow-up periods	NA

	Methods of analysis	Summary statistics and mapped distribution.
Results		The percentage of the total extent of blanket bog habitat (upland heathland habitat for comparison in brackets) burnt annually was 1.5% (3.0%) in the national sample dataset. Corresponding figures for the other areas were: 4.7% (5.4%) in the North York Moors, 2.5% (3.6%) in the North Pennines and 1.4% (1.9%) in the Peak District. If only the heather-dominated areas within the habitats (which are the most 'burnable' areas of the habitats and the parts where burning is most easily detectable from API) are considered, the figures are higher: 3.8% (4.5%) in the national dataset, 8.5% (7.5%) in the North York Moors, 6.7% (6.2%) in the North Pennines and 4.0% (4.2%) in the Peak District. The figures are similar for deep peat soils, e.g. 1.5% of deep peat nationally (3.7% of the heather-dominated area on deep peat). These figures give burn 'repeat times' for blanket bog habitat (heather-dominated part in brackets) of: 64 yr (26.5 yr) in the national dataset, 21.2 yr (11.7 yr) in the North York Moors, 39.3 yr (15 yr) in the North Pennines and 73.1 yr (25 yr) in the Peak District. The rate of burning on SSSIs (1.8% of blanket bog habitat and 4.0% of the heather-dominated area) was slightly greater than on non-SSSI (1.1% and 3.3%) in the national dataset. In the national sample, 38% of all burning was on blanket bog habitat and 46% on deep peat.
Notes	Limitations identified by author	
	Limitations identified by review team	In most cases the information is for a single point in time – repeat surveys would be beneficial to identify trends in burning extent and frequency.
	Evidence gaps and/or recommendations for further research	Limited information on trends in burning extent and frequency on blanket bog and other upland peatland habitats and for some areas of the uplands. Could be addressed in part by repeating the method on more recent aerial photos.
	Sources of funding	Natural England.

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)	h) What are the **extent**, **frequency**, practice and type of managed burning (including 'cool burning') on upland peatlands (including in relation to designated sites and water catchments)?

Study details	Authors	Yallop et al. 2006b [NB: ENRR 667 also refers to the same work and is also included in this assessment.]
	Year	2005/2006b
	Aim of study	To survey the national scale of fire managemnet and use historical photography to identify medium-term trends in its use
	Study design	Quantitative observational/correlation (sample survey/monitoring)
	Quality score	2+
	External validity	EV+
Population and setting	Source population	CS2000 Upland Environment Zone in England
	Eligible population	All area within zone eligible for inclusion in sample 1Km squares
	Inclusion and exclusion criteria	Systematic design to given even coverage

	Setting	Across English uplands
Methods of allocation to intervention/control	Methods of allocation	2% sample of 1 km squares (208) using random systematic design to give even coverage (with 2 samples per 10 km x 10 km 'block'). For change part of study, only original sample squares within National Parks used (only 23). In assessing photos moorland divided into just 2 recognisable types: "dwarf shrub heath" (including DS on bog etc) and graminoid-dominated.
	Intervention description	n/a
	Control/comparison description	n/a
	Sample sizes	2% (208 1 km sqs) and NP subsample (28)
	Baseline comparisons	1970s aerial photograghs
	Study sufficiently powered	n/a
Outcomes and methods of analysis (inc effect size, CIs for each outcome and significance)	Primary outcome measures	Area burned by age class. Aerial photograph examined to identify areas of vegetation that had been burnt and to then classify them to an age class. Where possible burn age was ground truthed or possible age refined using quadrat field data or from a known heather height/age relationship.
	Secondary outcome measures	Estimations of repeat time where made using simple equasion R = $^{D1+D2/C1+C2}$ based on Class's 1 and 2 alone
	Follow-up periods	n/a
	Methods of analysis	Baisc summary stats presented in main anaylsis of proportions burnt by age class and repeat times. For the change sub sample, paired t test and Wilcoxon signed rank test

		were used.
Results		Identified four classes of regrowth related to burning from aerial imagery. Visible evidence of burning was found consistently on dwarf shrub heath and bog.(71% of sample area) of which 17% by area had been burned in previous 4 years, equivalent to 114 km^2/yr. [Though not referred to, given the areas covered by heath and bog nationally, it is likely that a significant proportion, perhaps over half, of this is on deep peat.] In 51% of sample sites containing DSH/Calluna present it was possible to estimate a repeat time. Estimated repeat times lay between 14-25 years, median c.20 years. Within most of the NP subsample there had been a significant increase in the extent of new burns (from 15.1% to 29.7%) between the 1970s and 2000.
Notes	Limitations identified by author	Quality of, and difficulties in assessing, AP. No burning identified on grass/sedge-dominated moorland, though sample groundd data from Exmoor identified small extent burned. Suggests more difficult to ID from API due to transient nature of impact and less burnt. Difficulties in obtaining older AP to assess change (only done in NP subsample).
	Limitations identified by review team	Blanket bog/peat not separated from (but included in) wider heather/DS-dominated moorland. [Though recently addressed in new report yet to be assessed – could be incorporated with this assessment?] No mention of impact of grazing on vegetation recovery. Ground truthing limited and difficult.
	Evidence gaps and/or recommendations for	First large-scale analysis of the current burning practices in England. There is a need to extend this data set to include the extent and distribution of burning management, particularly on bogs even if they are already considered to be in a

	further research	degraded state. Such information may prove useful in determining the effects of prescribed burning on blanket bog and future condition
	Sources of funding	English Nature.