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	Daplyn, J. & Ewald, J.
	Year	2006
	Aim of study	To investigate the effect of keepering and burn management for grouse on the density of avifauna within moorland in the Peak District National Park at two scales: the moorland management unit and $1km^2$ or 2x2km tetrad land unit.
	Study design	Correlation
	Quality score	2-
	External validity	EV-
Population and setting	Source population	Moorland suitable for red grouse
	Eligible population	All moorland suitable for red grouse and within the PDNP
	Inclusion and exclusion criteria	All moorland areas for which bird density data are available for both census years 1990 and 2004

	Setting	Unmanaged and managed moorland within PDNP
Methods of allocation to intervention/control	Methods of allocation	Aerial photograph from 2001 defining burning polygons Surveys and interviews with shooting estates to (i) establish boundaries to moorland management units; (ii) define managed versus unmanaged areas; identify the presence and density of keepers.
	Intervention description	Moorland either subject to managed burning for the purpose of grouse shooting and where keepers are employed
	Control/comparison description	Moorland that may suffer some wildfire burns but where there are no keepers employed to undertake management for red grouse (e.g. predator control).
	Sample sizes	Data not provided 29 managed moorland units identified as having data for both bird census dates, equated to 64% of PDNP moorland area 5 areas of unmanaged moorland identified in the Kinder Scout region No quantification of total area of managed versus unmanaged or the sizes and spatial distributions of the different area types.
	Baseline comparisons	Bird densities from 1990 census
	Study sufficiently powered	Analysis of bird densities for management units (and unmanaged 'units') and for individual 1km^2 or 2x2km tetrads. Total numbers of observation units in either analytical approach not quoted explicitly.
Outcomes and methods of analysis (inc effect size, CIs for each	Primary outcome measures	Bird density data for 1990 & 2004 for moorland estate and land units Raptor data for 2004 for moorland estate and land units Proportion of moorland estate unit subject to burning (2001 data); the proportion of a

outcome and significance)		land unit covered by a burn polygon Proportion of moorland estate and land unit in each of 4 habitat category types (1988 data) Presence/absence of keepers for moorland estate units Density of keepers for a moorland estate unit. The proportion of a land unit covered by estates with grouse shooting
	Secondary outcome measures	
	Follow-up periods	14 years - 1990-2004 bird censuses
	Methods of analysis	Compositional analysis for habitat using MANOVA T-test for proportion of a moorland parcel burnt and the presence/absence of a keeper Generalised Linear Modelling and GLMixedM for bird densities in 1990, 2004 and the change between 1990 & 2004 in moorland estate units and land units, respectively. GLMM for raptor density data 2004 Wald statistic for GLMM
Results		Grouse moors had a higher composition of heath and mire, while other moors had more grass habitat ($P < 0.001$) The proportion of land burnt was higher on keepered land ($P=0.02$) Because of results are numerous a summary table is presented for each scale of the analysis:

Results summary at Scale of Management Unit (GLM):

Species	Keeper +/-								Keeper density	
	1990			2004			1990-2004		2004	
	B	B*	+/-	B	B*	+/-	B*	+/-	B	+/-
Dunlin							P<0.01	--		
Lapwing	P<0.05	P<0.05	+		P<0.05	+			P<0.05	+
M. Pipit	P<0.01									
R. Grouse	P<0.05			P<0.001	P<0.05	+	P<0.05	+	P<0.05	+
R. Ouzel				P<0.001	P<0.001	++	P<0.01	++	P<0.001	++
Skylark	P<0.001			P<0.001						
Snipe		P<0.01	++							
Twite	P<0.05			P<0.05			P<0.001	---		
Wheatear				P<0.05						
Whinchat	P<0.05	P<0.05	+							

Figures in blue indicate when habitat data have been factored in: the value of these results is questioned.

		Results summary at Scale of Land Unit (GLMM)

Species	1990		2004		1990-2004	
	B	+/-	B	+/-	B	+/-
Curlew			P<0.01	++	P<0.01	++
Dunlin	P<0.01	--				
Golden Plover			P<0.001	---		
Lapwing					P<0.05	+
M. Pipit	P<0.05	+			P<0.05	-
Red grouse			P<0.05	+		
Reed Bunting					P<0.01	--
Ring Ouzel					P<0.01	++
Skylark					P<0.05	-
Snipe					P<0.05	-
Wheatear					P<0.001	---
Whinchat					P<0.001	---

Merlin showed a +ive relationship to burning

Notes	Limitations identified by author	None
	Limitations identified by review team	Validity of using 1988 habitat data and assuming no change from 1990-2004. Assumption that the snap shot of burning in 2001 is an accurate reflection of that

		throughout 1990-2004. Loss of important information by amalgamating ecologically distinct habitats into very broad categories, e.g. Grassland, which combines improved grassland and e.g. *Molinia* grasslands. Consequently, the behaviour of species to habitat as a factor in response to burning cannot really be deduced from this study. Lack of information regarding relative sizes and spatial relationship of moorland management units and unmanaged units, which may affect the degree of independence of the two types of area. No account taken of grazing – the study appears to assume the area is either devoid of domestic grazers or that types of grazers and their stocking rates are constant across the PDNP, which would seem counterintuitive.
	Evidence gaps and/or recommendations for further research	Undertake similar study using improved habitat and burn data and include some consideration of the possible impact of grazing where it occurs.
	Sources of funding	Moors for the Future Partnership

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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 habitats?

Study details	Authors	Davies, G. Matt & Legg, Colin J.[Also see related Davies 2001.]
	Year	2008
	Aim of study	To determine how regular management burning of a northern Calluna vulgaris-dominated heathland affect the lichen diversity at the patch and landscape scale.
	Study design	Correlational
	Quality score	2+
	External validity	EV+
Population and setting	Source population	Upland *Calluna vulgaris* dominated heathland, Scotland
	Eligible population	Upland heather moorland managed under a traditional burning rotation. NVC H12 and H10. Patches burnt 3 months to 18 years previously.
	Inclusion and exclusion criteria	None detailed
	Setting	Mar Lodge Estate, Cairngorm National Park, Scottish Highlands

Methods of allocation to intervention/control	Methods of allocation	Based on information provided by gamekeeper/estate ecologist who provided information on which areas burnt when.
	Intervention description	Traditional moorland management with rotational burning.
	Control/comparison description	Areas which had not been burnt for at least 25 years (previously had been subject to traditional moorland management).
	Sample sizes	26 fires sites of different ages, 11 long-term unburnt sites. Only two lichen survey quadrats per site. Results from each quadrat used as independent sample points (though they are likely to be more closely related than sample points from different burns).
	Baseline comparisons	Baseline were sites that had not been burnt for c.25 years or more.
	Study sufficiently powered	Number of fire sites is adequate. Seems unlikely that two quadrats/burn site is sufficient to evaluate lichness richness, particularly given
Outcomes and methods of analysis (inc effect size, CIs for each outcome and significance)	Primary outcome measures	Lichen species richness
	Secondary outcome measures	
	Follow-up periods	None
	Methods of analysis	GLM and CCA
Results		A significant difference in the number and type of lichen species recorded in the two areas (P<0.001). Generally, across both sites, terricolous lichens were less frequent where pleurocarpous mosses

		were more abundant (P<0.005), and area 1 (wetter, on deep peat soils) had more pleurocarpous mosses and less terricolous lichen species. In area 1 (deep peat area), terricolous lichen richness was heavily dependent on *Calluna* stand development – in burnt areas, species richness increased with *Calluna* height, but decreased in unburnt areas (P<0.001). Corticolous (i.e. bark-living) species richness increased with *Calluna* stand height (P<0.001). CCA demonstrated significant relationships between species and sample site conditions, time since burn, altitude and soil moisture.
Notes	Limitations identified by author	No examination of effects of fire intensity on heathland lichens. Due to nature of study, no data on pre-fire vegetation and lichen communities – these would have provided much more meaningful information on lichen sensitivity to burning.
	Limitations identified by review team	Although authors recorded soil type and NVC community, the effects of these two variables on lichen diversity and susceptibility to fire were not reported. A number of other variables needed to be controlled for: eg grazing, level of trampling, size of fire, intensity.
	Evidence gaps and/or recommendations for further research	Effects of fire intensity on lichen survival. Authors suggest that severe fires, that ignite moss or peat, are likely to eradicate lichen populations from significant areas for extended periods.
	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)	Is there a relationship between managed burning of upland peatlands and 'wildfire' (risk, hazard, intensity, extent and damage)?

Study details	Authors	Davies, G M and Legg, C J
	Year	2011
	Aim of study	To determine the role of weather and soil moisture in governing ignition and sustained combustion of Calluna fires, to model the probability of ignition based on fuel moisture content and to model the rate of spread of small, developing fires.
	Study design	Experimental/monitoring/correlation.
	Quality score	2+
	External validity	+
Population and setting	Source population	Upland Calluna – dominated moorland.
	Eligible population	Heather stands at experimental sites in Pentland Hills and SE Highlands, Scotland.
	Inclusion and exclusion criteria	Chose sites in 'late building' phase heather on flat ground. Justified as this is the 'fuel' typically burned by managers. Areas with Vaccinium or Empetrum excluded.

	Setting	Upland Calluna heath (probably NVC H12 but not reported in study).
Methods of allocation to intervention/control	Methods of allocation	Sample plots in Calluna-dominated heath. Siting of plots not explained. Within plots 2x2 m sample areas were allocated (method of allocation not explained) and fuel load and structure measured in a systematic layout within the sample plot.
	Intervention description	Burning by point or line ignition using a drip torch. Fires were attempted at two times approx 11.am and 3 pm.
	Control/comparison description	No comparison with untreated areas -
	Sample sizes	2 2x2 m plots per fire – 20 ignition attempts
	Baseline comparisons	Fuel loads estimated in plots pre-treatment.
	Study sufficiently powered	Not randomised. Small sample applicable to limited range of conditions (vegetation type and stand age).
Outcomes and methods of analysis (inc effect size, CIs for each outcome and significance)	Primary outcome measures	Prediction of the probability of successful ignition based on moisture content of fuel.
	Secondary outcome measures	None.
	Follow-up periods	None.
	Methods of analysis	Regression and factor analysis used to assess the relationships between fuel moisture content in the components of the vegetation. Logistic regression used to model the probability of ignition success.

Results		Demonstrated that at fuel moisture content >c. 70% ignitions failed. With moisture content less than 60% fires developed rapidly. Initial spread of fire is primarily controlled by moisture content in lower canopy/moss and litter layer.
Notes	Limitations identified by author	Limited to fires in a single fuel type. Experiments did not adequately address other factors e.g. windspeed or other weather variables.
	Limitations identified by review team	Study conducted in the legal burning season only. Small sample size – study identifies small scale variation in fuel structure even in apparently homogenous Calluna stands. Study addresses fire risk from small scale (point) ignition sources of limited duration (e.g. cigarette) but not larger (e.g. 'escaped managed fire) or more sustained source (e.g. barbecue).
	Evidence gaps and/or recommendations for further research	Extend research to other vegetation types (e.g. heather stands on blanket bog). Consider characteristics of older heather stands (i.e. those likely to be encouraged by management regimes promoting biodiversity).
	Sources of funding	Scottish Wildfire Forum and SNH.

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Review Question(s)	Is there a relationship between managed burning of upland peatlands and 'wildfire' (risk, hazard, intensity, extent and damage)?

Study details	Authors	Davies, G M
	Year	2005
	Aim of study	The aim of this project is to describe the functional relationships that exist between fire behaviour, its impact on the environment, and fuel and weather conditions on heather (Calluna vulgaris Hull.) moorland in the north-east of Scotland.
	Study design	Randomised controlled trial
	Quality score	2+
	External validity	+
Population and setting	Source population	Moorland
	Eligible population	
	Inclusion and exclusion criteria	

	Setting	Heather moorland in the south Scottish Highlands
Methods of allocation to intervention/control	Methods of allocation	
	Intervention description	
	Control/comparison description	
	Sample sizes	
	Baseline comparisons	
	Study sufficiently powered	
Outcomes and methods of analysis (inc effect size, CIs for each outcome and significance)	Primary outcome measures	
	Secondary outcome measures	
	Follow-up periods	
	Methods of analysis	
Results		See below
Notes	Limitations identified by author	
	Limitations identified by	

	review team	
	Evidence gaps and/or recommendations for further research	
	Sources of funding	GWCT Studentship

Davies' PhD Thesis deals mainly with methods of predicting fire behaviour. His study sites were mainly in the Scottish Highlands mainly in heath in which Calluna is dominant and in stands that were within the range of conditions that would be subject to management fires.

The summary below gives the main chapter headings (bold) and some relevant findings.

Non-destructive Methods for Estimating Heathland Fuel Load and Structure.
Calluna height (a proxy for stand age) shows no relationship with the ratio of dead to live fuels despite the expectation that this will gradually increase as stands age.

Variation in the Moisture Content of Moorland Fuels: implications for fire management.

The amount of water held in fuel particles is of vital importance to fire behaviour. The fuel moisture content (FMC) of both live and dead fuel components affects the duration of preheating and amount of energy required to raise fuel to combustion temperature (Pyne et al.. 1996), rates of combustion and the amount of energy released (Byram 1959). High moisture contents reduce fire risk, intensity and spread as energy produced by a fire must first be used to drive off excess moisture while the production of large quantities of steam may have a smothering affect on the combustion process by reducing the oxygen concentration of surrounding air (Catchpole & Catchpole 1991)

Small scale spatial variation: Relatively little variation was detected between the mean of the FMCs of individual fuel components or stratigraphic layers . The exception to this general rule was the extremely low FMC of dead fuels. It is noticeable that in both building and mature phase Calluna the moisture content of canopy material and small diameter stems (55 –70% DW) is less than that of larger woody stems (75 – 80% DW). The FMC of basal canopy Calluna appears to be generally lower than either other material in the canopy or woody stems.

Seasonal and diurnal variation investigated. Studies indicated that variability in Calluna moisture content is relatively similar spatially but varies significantly according to season.

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Fire Behaviour on Calluna-dominated Moorlands: Controls on Prescribed Fire Behaviour.

FMC plays an important role in fire behaviour with increased moisture contents leading to slower moving, less intense fires with smaller flames

Increased temperatures and durations above 400$_o$C in the canopy layer are correlated with higher fuel loads, lower humidity and fuel moisture and are also influenced by greater quantities of dead fuels. Although increases in below ground temperatures were never more than a few degrees these are nevertheless greater where fires are slower moving and hence less intense but have greater residence times.

Vegetation height is important as it is not only strongly correlated with total and fine fuel loading but the height of the canopy above the ground may govern the degree of aeration of the fuel and thus oxygen supply for combustion. Old stands with heterogeneous canopies also have greater surface roughness which leads to turbulent air flow, greater penetration of air movement into the canopy and thus drying of fuels as well as an improved supply of oxygen for combustion. In older canopies there is, therefore, not just a continuous oxygen supply but also significantly less heat and time is needed to evaporate water before pyrolysis and combustion can begin. Fires in such conditions are more akin to miniature crown fires rather than the traditional perception of a surface fire which spreads through dead litter on the ground surface.

Fires in older fuels burn faster and hotter than those in younger fuels and are more prone to rapid changes in behaviour associated with changing weather conditions. We know from the work of several authors (Cheney et al. 1993, Fernandes 2001) as well as Hobbs and Gimingham (1984) that fires spread faster with higher intensities where fire widths are greater and we must therefore consider whether a blanket advice of 30-m wide fires (based on habitat usage by red grouse) is appropriate and whether when burning in higher fuel loads it is advisable to burn smaller fires.

Fire Behaviour on Calluna-dominated Moorlands: Ground-truthing Fire Behaviour .

Dull

Fire Behaviour on Calluna-dominated Moorlands: The Nature of Fire Severity.

Stand age with the associated development of mats of pleurocarpous mosses and the loss of ability to regenerate vegetatively that decides how burning will affect regeneration. Burning heather of twenty years or more will, in sites such as ours, lead to vegetation consisting of a dead or dying moss layer with occasional Vaccinium plants, coarse grasses and little evidence of Calluna regeneration:

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Review Question(s)	Is there a relationship between managed burning of upland peatlands and 'wildfire' (risk, hazard, intensity, extent and damage etc.)?

Study details	Authors	Davies, G.M., Legg, C.J., O'Hara, R.O., MacDonald, A.J. & Smith, A.A.
	Year	2010[a]
	Aim of study	To investigate spatial and temporal variation in the fuel moisture content (FMC) of *Calluna vulgaris*
	Study design	Correlation
	Quality score	2+
	External validity	EV +
Population and setting	Source population	Scottish upland
	Eligible population	5 geographically dispersed sites with Calluna heath
	Inclusion and exclusion criteria	Upland stands dominated by Calluna and vulnerable to wildfire Accessibility Broad similarities in vegetation and soils

	Setting	Upland heath NVC types H10, H12 & H16 over peat to 30cm+
Methods of allocation to intervention/control	Methods of allocation	Samples segregated according to: detailed pre-defined vertical canopy stratification (top foliage above general canopy, top & bottom half of canopy, 10cm incremental distance classes for each of living & dead stems defined from canopy base); 3 x diameter classes for stems (live & dead). Samples obtained from different geographic sites Sampling areas defined using randomised 50cm x 50cm quadrat and 10cm x 10cm subquadrat locations Samples for exposure study selected by random walk technique followed by stratified sampling of bushes taller than surrounding vegetation
	Intervention description	No intervention. Exploration of variation in FMC within canopy, over time, between seasons and in response to exposure.
	Control/comparison description	Comparisons of FMC: (1) among different fuel components of the canopy for a number of sites sampled in different seasons in 2 sampling years; (2) among fuel components sampled from one site in 2 seasons (4 weeks in autumn & 8 weeks in spring); (3) between exposed and sheltered live foliage after extreme climatic conditions in early spring.
	Sample sizes	Study (1) = 141 samples total (3 sites, 8 sampling dates,2-8 quadrats with 2-8 subquadrats sampled therein - Table 2) Study (2) = ca. 380-400 samples for Site 2 (max. possible is 404 but some sampling days were lost to snow cover, exact final total not provided) plus 60 in an independent study at Site 5 Study (3) = 38 samples [(7 plants x 2 aspects x 2 sampling occasions) + (5 plants x 2 aspects)]

	Baseline comparisons	N/A
	Study sufficiently powered	Designs do not optimise power but appropriate statistical approaches adopted for exploring and apportioning sources of variation
Outcomes and methods of analysis (inc effect size, CIs for each outcome and significance)	Primary outcome measures	Fuel moisture content (FMC) of multiple fuel components in Calluna canopy segregated by vertical stratification and size, incorporating live and dead tissues, foliage and stems. FMC of ground layer of litter & moss
	Secondary outcome measures	None
	Follow-up periods	Study (1) covered spring 2003 , spring & summer 2006 but not at all sites Study (2) was undertaken daily throughout 2 month autumn period and a 2 month period during the following spring, supplemented by data from a 6 day period between the end of February and early April at a second site in an independent study. Study (3) covered 3 single occasions of extreme weather in one month.
	Methods of analysis	Study (1) Linear Random effects model fitted by restricted maximum likelihood (REML), for each fuel type Study (2) Not made clear in paper. Coefficients of variance are referred to but not presented. Study (3) Linear mixed effects model fitted by REML. Estimates of p-values fitted using 'pvals.fnc' of 'languageR' package as well as AIC using maximum likelihood. Differences in fit were tested using 'aov' function.
Results		FMC of individual canopy fuel components is variable

		Moisture content declines consistently deeper into the canopy: stem moisture does not show the same gradient but thin stems have lower FMC than the canopy or thicker stems Dead material has a much lower FMC , which is affected by ambient conditions FMC for some fuel components shows as considerable variation over small spatial scales, which may make managed burning less predictable (e.g. suppression among damp patches). Live fuel components tended to vary more between sites than over small spatial scales Large changes in FMC occur between seasons compared to relatively small day-to-day changes attributable to active water management by plants. FMC is highest in summer because of the flush of new growth, and lower in spring and autumn. Frozen ground was associated with the lowest FMC values in live components: the response varies spatially and depends on other environmental conditions. Such low FMC values are likely to be associated with fire hazard and correspond with conditions leading to winter browning and subsequent canopy die-back.
Notes	Limitations identified by author	Season and site effects were confounded preventing statistically robust conclusions about causes of the difference in FMC between summer, autumn & spring. Analysis data separately for each fuel type in study (1) means differences in spatial and temporal variability among these cannot be afforded any statistical significance.
	Limitations identified by review team	No consideration of the possible impact of grazing, whether from domestic or wild herbivores.
	Evidence gaps and/or recommendations for further research	Undertake similar work for other growth phases of Calluna to provide a more complete picture of FMC behaviour. Explore relationships with altitude and Calluna in mire types rather than heath vegetation.

		Investigate how grazing may affect FMC and thus fire risk.
	Sources of funding	NERC, Game & Wildlife Conservation Trust, Scottish Government, SNH.

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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	Dennis, RLH and Eales, T
	Year	1997
	Aim of study	Assessment of the influence of isolation, patch area and patch quality on occupancy by Large Heath butterfly.
	Study design	Survey and correlation/experimental
	Quality score	2+
	External validity	+
Population and setting	Source population	Northumberland – potentially suitable habitat for Large Heath.
	Eligible population	166 sites – 90 identified from previous survey and 76 identified as potential sites from habitat maps.
	Inclusion and exclusion criteria	Sites known to be occupied from previous survey and additional ones within the Northumberland National Park at which suitable habitat was present. Additional sites

		outside the National Park do not seem to have been considered.
	Setting	Oligotrophic bogs (blanket, raised and valley bogs) with Eriophorum vaginatum and Erica tetralix
Methods of allocation to intervention/control	Methods of allocation	All potentially occupied sites surveyed except 12 missed due to poor weather.
	Intervention description	n/a
	Control/comparison description	n/a
	Sample sizes	n/a
	Baseline comparisons	None.
	Study sufficiently powered	Not randomised. Some multivariate analyses but these are not fully reported.
Outcomes and methods of analysis (inc effect size, CIs for each outcome and significance)	Primary outcome measures	Presence / absence of and measures of site quality for Large Heath butterfly.
	Secondary outcome measures	None.
	Follow-up periods	None
	Methods of analysis	Correlation, regression and discriminant function analysis.
Results		Large Heath butterfly was found at 76% of sites surveyed. All sites occupied are between 140 and 410m OD and have a mean size of 22ha (range 1 -170ha). They range

		in isolation from 10m to 30km. Habitat quality, patch size and isolation account for 61% of variation in occupancy. Most favoured habitats are those with dense, vigorous growth of Eriophorum vaginatum and Erica tetralix on sheltered mires. Frequent burning is likely to render sites unsuitable but occasional burning may be beneficial in reversing succession.
Notes	Limitations identified by author	Measures of site isolation may underestimate the significance of this factor. Difficulties of recording due to short flight season, poor weather in occupied habitats and difficulty of finding pre-adult stages.
	Limitations identified by review team	Validity of site selection not discussed and based on existing understanding of habitat requirements.
	Evidence gaps and/or recommendations for further research	Better elucidation of habitat factors that influence the Large Heath.
	Sources of funding	?Some or all of: Butterfly Conservation, BES, EN, Forest Enterprise, MOD, Northumberland NP, Northumberland WT

Dennis and Eales investigated the effects of habitat quality, isolation and patch area on occupancy of Large Heat butterfly in Northumberland. The county has around 72% of the known occupied sites for this species. They identified for survey 166 sites – 90 identified from previous survey and 76 identified as potential sites from habitat maps.
For each site presence/absence, of the butterfly, isolation from nearest occupied patch, patch area and measures of habitat quality were recorded.

Large Heath butterfly was found at 76% of sites surveyed. All sites occupied are between 140 and 410m OD and have a mean size of 22ha (range 1 -170ha). They range in isolation from 10m to 30km. Habitat quality, patch size and isolation account for 61% of variation in occupancy.

Though bogs are the habitat most likely to be occupied Large Heath butterflies were also found in wet and dry heath, acidic and marshy grassland. Sites where the butterfly was not found had a greater proportion of heath than bog. Most favoured habitats are those with dense, vigorous growth of Eriophorum vaginatum and Erica tetralix on sheltered mires. Frequent burning is likely to render sites unsuitable but occasional burning may be beneficial in reversing succession.   Larger sites and those closest to other occupied sites are most likely to be occupied.

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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	Elliott, R.J.
	Year	1953
	Aim of study	To investigate the effect of burning on heathland in the South Pennines
	Study design	Correlation – space for time replacement chronosequence
	Quality score	2-
	External validity	EV-
Population and setting	Source population	North England, South Pennines, Sheffield
	Eligible population	Moorland *Callunetum*
	Inclusion and exclusion criteria	Area accessible easily from Sheffield Area with permitted access and with burn history
	Setting	7 distinct moorland locations on South Pennines within 10 miles west of Sheffield.

Methods of allocation to intervention/control	Methods of allocation	Burn age stands defined from Calluna growth rings, eye witnesses and keepers
	Intervention description	Burning – short rotation (ca. 10yrs)
	Control/comparison description	Burning long rotation (20yrs)
	Sample sizes	50, 0.5m x 0.5m quadrats on each sampling occasion within each age stand (*seasons since burnt with linked figures indicating stands sampled over more than one season such that age changes*) 7 sites Bamford – 5 stands (*1 yr; 2-3;4-5-6; 11-12-13; 20+-20+*) Toadsmouth – 4 stands (*3yr; 2-3; 8-9; 20+-20+*) Ringinglow - 4 stands (*3; 2-3; 8-9; 20+*) Lodgemoor – 3 stands (*3-4-5; 4-5; 10-11-12; 20+-20+-20+*) Hallam – 2 stands (*1; 9*) Hound Kirk – 1 stand (*20+*) Houndkirk Hill – 3 stands (*2 x 2; 20+)* 1 figure for frequency on each occasion Cover determined from 100, 5cm x 5cm sub-cells of the 0.5m x 0.5m frequency quadrat.
	Baseline comparisons	Values from 20+ yr stands, representing oldest burns
	Study sufficiently powered	Less well powered than appears at first because certain stands are used in successive seasons.

		No statistical analysis undertaken
Outcomes and methods of analysis (inc effect size, CIs for each outcome and significance)	Primary outcome measures	Frequency among 50 quadrats % cover for 50 quadrats
	Secondary outcome measures	% cover values assigned to 3 categories (dominant, significant & insignificant) for >50%, 10-50% & >10% cover, respectively
	Follow-up periods	Differs among stands 10 stands are sampled once 9 stands are sampled twice in successive burn 'seasons' 5 stands are sampled over 3 successive seasons NB: It appears that successive burn seasons may be only 4 months apart as April was taken as the burn month
	Methods of analysis	Qualitative comparative No statistical analysis
Results		Trends only – no statistical precision & some data sets are not independent, being acquired from the same stand within a 4 or 12 month period. *Empetrum nigrum* – declines initially in the first years following burning but is not eliminated by burning *Vaccinium myrtillus* - increases initially in the first year following burning; - regular burning appears detrimental as there is a progressive loss from areas with a

		short cycle. *Vaccinium vitis-idaea* – reduced by burning – eliminated by short cycle burning *Deschampsia flexuosa* – increases temporarily over 1st ca. 6yrs but declines from 10yrs thereafter as *Calluna* dominates increasingly; - shortening the burn is expected to decrease it as *Calluna* dominates more rapidly when rejuvenating from young stands
Notes	Limitations identified by author	Alludes to potential confounding environmental factors but uses comparisons between short and long cycle sites and among different burn age stands to contend that burn responses are dominant.
	Limitations identified by review team	Effect of potential confounding environmental factors are exacerbated by repeated monitoring of some stands over successive burn seasons, especially as the interval between them may be as little as 4 months. This makes the study appear, at first glance, more powerful than it is. Lack of statistical analysis weakens the conclusions that can be drawn. Text does not provide sufficient explanation for some methodological aspects of the study. Legends insufficient for a clear understanding of table entries. Specific reference is made to grazing pressure for only one site (Ringinglow: sheep noted as being present consistently). The interaction of burning and grazing is

		considered only superficially and not at all in the consideration of individual species' responses to burning and the length of burn cycle.
	Evidence gaps and/or recommendations for further research	Thesis very dated. More modern studies have addressed similar issues and have included environmental data (Harris et al. 2006)
	Sources of funding	Not acknowledged

Elliott (1953) studied of the effects of burning on 7 heather-dominated moorland stands (Callunetum) in the South Pennines, all located within 10 miles of Sheffield. Some sites had been subject to systematic managed burning whilst others had fallen victim to accidental fire. In the South Pennines Callunetum is noted as characteristically species-poor (suggested as the consequence of long term historic burn management) and only 10 species were consistent among the stands. The age of each burn was estimated by assessing the frequency distribution of growth rings in *Calluna*, for which the growth forms present were also noted. This enabled the origin of the population to be determined from the relative abundance of plants derived from seedling establishment versus vegetative re-growth.

The frequency of individual species in each stand was determined using 50, 0.5m x 0.5m quadrats located at random throughout the area. Some stands were sampled one or more successive seasons after the initial assessment, at which point their age status changed accordingly. Percentage cover data were estimated on one occasion from a smaller number of 0.5m x 0.5m quadrats subdivided into 100, 0.05 x 0.05m cells. These were then assigned to one of three categories of cover: dominant (>50% cover), significant (10-50%) and insignificant (<10% cover). Both data sets were used to compare qualitatively: the performance of species between long and short cycle burns, and between systematic and irregular burning; and the role of vegetative re-growth versus seedling recruitment.

Key changes in response to burning were suggested as:
an initial decline in *Empetrum nigrum* but no evidence of eventual elimination under regular burning;
an initial increase in *Vaccinium myrtillus*, for which regular burning is detrimental and a shorter cycle leads to progressive loss ;
a reduction in *Vaccinium vitis-idaea* and its eventual elimination under a regime of repeated burning;
a temporary increase in *Deschampsia flexuosa* up to approximately 6yrs after burning, after which it starts to decline.

It is suggested from the data that systematic burning with a short burn cycle will eventually lead to the loss of *Deschampsia* because of the increasing dominance of *Calluna*, which regenerates more rapidly from young stands, thus reducing the period over which *Deschampsia* can exploit reduced competition in the community.

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) What are the effects of managed burning on the maintenance and restoration of the characteristic floristic composition, structure and function of upland peatland habitats?

Study details	Authors	Ellis, CJ
	Year	2008
	Aim of study	Look at interactions between hydrology, burning and contrasting plant groups during millennial-scale development of sub-montane wet heath using pollen core analysis
	Study design	Cohort study? Interrupted time series?
	Quality score	3+
	External validity	EV-
Population and setting	Source population	Western Rannoch Moor, north west Scotland
	Eligible population	3 cores, of entire peat depth >100m apart, plus a further monolith about 1km from main site. All shallow peat, approx 1m depth, NVC community M17 Scirpus cespitosus – Eriophorum vaginatum (Deergrass - Hare's-tail Cotton grass)
	Inclusion and exclusion criteria	Presumably these were chosen as being of similar vegetation types. However no explanation of how locations were selected has been given, nor if anything has been

		excluded from the sample.
	Setting	This community is the characteristic blanket bog vegetation of the more oceanic parts of Britain, occurring extensively on waterlogged ombrogenous peat. It is a community of lower altitudes where extreme humidity is combined with a relatively mild winter climate. It is largely confined to western Britain from the western Highlands of Scotland and the Western Isles, to south-west Scotland, the Lake District, Wales and south-west England.
Methods of allocation to intervention/control	Methods of allocation	
	Intervention description	
	Control/comparison description	
	Sample sizes	• Pollen analysis on 0.5cm^{3}peat samples at 4cm intervals extracted from the core was used to match synchronous stratigraphic horizons between the cores in the same peat system, based on previously identified pollen zones. • Five horizons from the monolith were submitted for radio-carbon dating to calculate calibrated years before present (cal. Yr BP). • Macrofossils (including macroscopic charcoal) were examined from 1cm^3 samples extracted from the cores at 2cm intervals. • Humic acid was measured from 1cm^3 peat samples extracted from the cores as 1 or 2cm intervals. Humic acid is used as a proxy measure rate of decomposition and therefore of surface moisture.
	Baseline comparisons	Pollen diagrams matched with previous studies for Rannoch Moor (Walker & Lowe 1977, 1979, 1981)

	Study sufficiently powered	Seems reasonable, but in reality only 3 replicates and some of the outcomes are only found in one core. May need more replicates for really strong relationships?
Outcomes and methods of analysis (inc effect size, CIs for each outcome and significance)	Primary outcome measures	They were able to measure the relative abundance of macrofossils of Sphagnum (bog mosses), Ericaceae (e.g. Calluna vulgaris, Erica tetralix), Racomitrium (woolly fringe moss) and Monocotyledons (Eriophorum angustifolium, E.vaginatum, Scirpus cespitosus), also charcoal remains and levels of humic acid as a proxy measure for surface wetness.
	Secondary outcome measures	Pollen diagrams used to identify synchronous horizons between the 4 cores. Radiocarbon-dating of the monolith suggests approximate dates.
	Follow-up periods	This is a one-off study, but looking at a very long time scale.
	Methods of analysis	• Positions of pollen horizons within the peat stratigraphies were statistically confirmed using a Mann-Whitney U-test to compare values of % TLP (total land pollen) for key pollen taxa. • Presence-absence of macrofossil species and charcoal was compared within individual cores to values of % transmission using logistic regression analysis with a logit link function (macrofossils), and, for charcoal a Mann Whitney U-test. • Relationships between the % frequencies of contrasting macrofossil classes were examined for horizons in the three stratigraphies combined using Spearman's rank correlation
Results		Radiocarbon dating suggests peat accumulation began during early post glacial, ca. 9525 cal yr BP. Rate of peat accumulation has been slow, 1.46 ±0.45cm/100years. Pollen spectra based on selected taxa matched two pollen assemblage zones previously identified in other studies

		These horizons are found in all three cores, setting a context for reconstruction of vegetation development, local burning and surface hydrology. They found • higher levels of macrofossil charcoal with lower levels of surface moisture (inferred from humic acid levels). This was statistically significant for 2 of the 3 cores (*U*=21, *p*=0.019 and *U*=221.5, *p*=0.032). • higher Sphagnum and monocotyledon macrofossil remains associated with increased surface moisture, again in 2 of 3 cores. • % charcoal was negatively correlated with Racomitrium (p=-0.1599)and monocotyledon (p=-0.2155) remains. • % frequencies of Ericaceae are negatively correlated with monocotyledon remains. (p=-0.1796) • Racomitrium, Sphagnum and Ericaceae are positively correlated with one another. (p values of 0.2302, 0.2348 and 0.2079) • Less significantly Racomitrium remains are associated with increased surface moisture but only in 1 core and Ericaceae remains associated with lower surface moisture but again only in 1 core. These results are used to suggest a hypothetical framework for environment-vegetation interactions during millennial scale wet heath development. This is best illustrated by the diagram provided in the paper. Contrasting plant groups respond to changes in local surface hydrology driven by climatic variation and landscape-scale change (e.g. deforestation) Drier conditions, along with more burning are associated with more Ericaceae and

		Racomitrium. Wetter conditions, along with less burning are associated with more Moncotyledons and Sphagnum. However the physical processes of hydrology and burning may be modified by long-term vegetation interactions, e.g. that monocotyledons are negatively associated with Ericaceae (cf competition) and that Ericaceae and the mosses Racomitrium and Sphagnum are positively associated (cf facilitation)
Notes	Limitations identified by author	The link between surface moisture and rates of decomposition (measured here by amount of humic acid) may be weakened by species-specific decay rates. Variation in humic acid tentatively indicates periodic shifts in local hydrology. However correlated trends between discrete cores support the idea that regional or landscape-scale events have caused changes in surface moisture across the whole of the wet heath
	Limitations identified by review team	Difficult to comment on this as I am not familiar with this type of work and it is obviously heavily cross-referenced to a huge body of work on peat pollen analysis. It is written in quite technical language that could possibly have simplified to make it more accessible to a larger group of interested people
	Evidence gaps and/or recommendations for further research	It might be useful to test the model somehow, possibly by looking at plant interactions of a site which is re-wetted. Would expect a shift to more monocotyledons and Sphagnum? As the link between burning and surface dryness was not really clarified, there may be further work here? Is there more burning because it is already dry and there are more ericaceous shrubs? Is the surface drier because there is more burning? It might help to look at this paper alongside either other research which looks at the impact of burning and this proxy measure of surface wetness or may need new research?

	Sources of funding	Funded as a BBSRC studentship

3 cores, of entire peat depth >100m apart, were taken from Western Rannoch Moor, north west Scotland A further monolith was dug, about 1km from main site. All were on shallow peat, approx 1m depth, NVC community M17 Scirpus cespitosus – Eriophorum vaginatum (Deergrass - Hare's-tail Cotton grass). This is described as a wet heath community on shallow peat, characteristic of western, oceanic climates.

Pollen analysis was used to match synchronous stratigraphic horizons between the cores in the same peat system, based on previously identified pollen zones. Five horizons from the monolith were submitted for radio-carbon dating to calculate calibrated years before present (cal. Yr BP). Macrofossils (including macroscopic charcoal) were examined from $1cm^3$ samples extracted from the cores at 2cm intervals. Macrofossils were scored into four contrasting plant groups: Racomitrium, Sphagnum spp., Ericaceae and Monocotyledon remains (mainly Eriophorum and Scirpus spp). Humic acid was measured from $1cm^3$ peat samples extracted from the cores as 1 or 2cm intervals. Humic acid is used as a proxy measure rate of decomposition and therefore of surface moisture.

They found

- higher levels of macrofossil charcoal with lower levels of surface moisture (inferred from humic acid levels).
- higher Sphagnum and monocotyledon macrofossil remains associated with increased surface moisture, again in 2 of 3 cores.
- % charcoal was negatively correlated with Racomitrium and monocotyledon remains.
- % frequencies of Ericaceae are negatively correlated with monocotyledon remains.
- Racomitrium, Sphagnum and Ericaceae are positively correlated with one another.
- Less significantly Racomitrium remains are associated with increased surface moisture but only in 1 core and Ericaceae remains associated with lower surface moisture but again only in 1 core.

These results are used to suggest a hypothetical framework for environment-vegetation interactions during millennial scale wet heath development. This is best illustrated by the diagram provided in the paper.

Contrasting plant groups respond to changes in local surface hydrology driven by climatic variation and landscape-scale change (e.g. deforestation)

Drier conditions, along with more burning are associated with more Ericaceae and Racomitrium.

Wetter conditions, along with less burning are associated with more Moncotyledons and Sphagnum.

However the physical processes of hydrology and burning may be modified by long-term vegetation interactions, e.g. that monocotyledons are negatively associated with Ericaceae (cf competition) and that Ericaceae and the mosses Racomitrium and Sphagnum are positively associated (cf facilitation).

Seperating the confounding effects of surface hydrology and burning on long-term vegetation development is difficult and further complicated by evidence that species interactions may have modified the vegetation response. The results indicate that while burning has been a long – term feature of the wet heath vegetation is does not uniformly encourage ericaceous shrubs and preclude Sphagnum (as often perceived). Remains of Ericaceae are not associated with the charcoal record, but are associated with Sphagnum and Racomitrium. These positive associations may be attributed to the regenerative growth of ericaceous shrubs by layering into an intact moss carpet and the sustained growth of mosses around a structural matrix of ericaceous shrubs.

They suggest that wet heath vegetation is relatively stable with the vegetation dynamics able to modify and buffer (?) the effects of larger scale climate and burning effects. However the loss or change of plant groupings e.g. through pollution or over-grazing may disrupt this process.

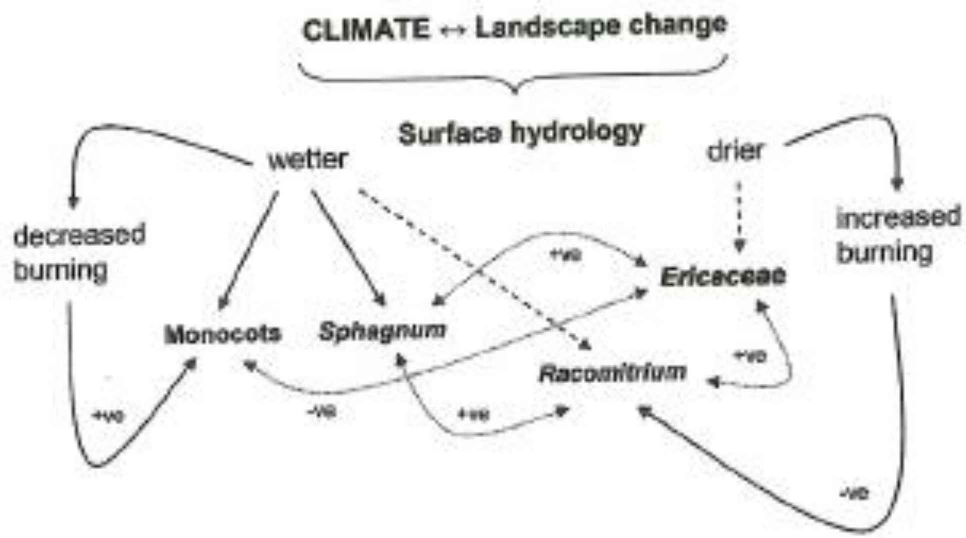

Fig. 6. Hypothetical relationships between environmental drivers and plant groups, tentatively inferred from the palaeoecological record as contributing to the long-term stability of wet heath development. Contrasting plant groups respond to changes in local surface hydrology driven by climatic variation and landscape-scale change (e.g. deforestation). The effect of surface hydrology may be direct or indirect (via burning), strong (solid line) or weaker (dashed line). However, the physical processes of hydrology and burning may be modified by long-term vegetation interactions (dotted lines identify positive +ve, or negative –ve correlations) which may occur independently of burning and hydrology: e.g. negative associations between monocotyledons and *Ericaceae* (cf. competition) and positive associations between *Ericaceae* and the mosses *Racomitrium* and *Sphagnum* spp. (cf. facilitation).

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	Eyre, MD, Luff , ML and Woodward, JC
	Year	2003
	Aim of study	To outline the distribution of ground beetle, rove beetle spider and plant bug species assemblages on grouse moor in S Scotland and the occurrence of nationally rare and scarce invertebrate species.
	Study design	2: survey/correlation.
	Quality score	2+
	External validity	+
Population and setting	Source population	Grouse moorland in Newcastleton-Langholm SSSI, S W Scotland.
	Eligible population	Habitats: Wet Calluna, Eriphorum and Vaccinium moor; Molinia moor; Dry Calluna moor; grassy streamsides with bracken.
	Inclusion and exclusion	Not defined.

	criteria	
	Setting	Upland moorland
Methods of allocation to intervention/control	Methods of allocation	59 sample sites in 4 habitat types with 4 management categories.
	Intervention description	Unmanaged, sheep grazed, Herbicide and burning, fire or cutting
	Control/comparison description	Differences in invertebrate assemblage.
	Sample sizes	59 sample sites each with 9 replicates in each year 1992-1996 (May – October and collected at 5 monthly intervals). Suction sampling at 47 sites each with 2 replicates collected on one day (August) in each of 4 years – 1993 -1996.
	Baseline comparisons	None.
	Study sufficiently powered	No – n/a
Outcomes and methods of analysis (inc effect size, CIs for each outcome and significance)	Primary outcome measures	Ground beetle. Rove beetle, spider and plant bug species assemblages. Site quality scores.
	Secondary outcome measures	None.
	Follow-up periods	n/a
	Methods of analysis	Ordination (DECORANA and CANOCO) used to investigate influences on distribution of species assemblages and relate these to land cover and soil type. Ordination axes used as a basis for classification of assemblage. Site quality scores derived.

Results		Ground beetle assemblages as defined by classification were related to habitat structure rather than vegetation type or management except that one group was predominantly in bare areas created by Molinia control.
Notes	Limitations identified by author	Recognised potential effect of soil and topography variables.
	Limitations identified by review team	Sample strategy not explained. Incomplete habitat vs treatment matrix. Environmental factors and vegetation at sample locations not described adequately.
	Evidence gaps and/or recommendations for further research	Factorial treatment relating invertebrate assemblage to management.
	Sources of funding	Buccleugh Estates and SNH?

Evidence Table

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

Study details	Authors	Farage, P, Ball, A, McGenity, T J, Whitby, C and Pretty, J
	Year	(2009)
	Aim of study	To assess direct losses of carbon from vegetation burning and consider the potential impact of burning on the carbon cycle as a whole through consideration of greenhouse gas fluxes using best estimations from published values in similar environments.
	Study design	2:Carbon budget study: comparison/correlation study; or could be classed as 3: case-study.
	Quality score	2-
	External validity	-
Population and setting	Source population	Mossdale Moor, North Yorkshire
	Eligible population	Heather moorland subject to rotational burning
	Inclusion and exclusion criteria	Samples in recent burn (last month), stands 12-15 years after fire and 25 years after fire.

	Setting	Upland moorland – heath on deep peat?
Methods of allocation to intervention/control	Methods of allocation	Not reported.
	Intervention description	Rotational burning on nominal 15-20 year cycle with grazing at -.65 sheep / ha.
	Control/comparison description	Stands not burned for 25 years.
	Sample sizes	Biomass sampled in 12 or 16 subplots in 1 stand in each heather age class (?). Losses from burning sampled in unreported number of plots in two years. Below ground biomass (n=3 x1) , soil cores (n=3 x4) sampled in areas sampled for biomass. Soil respiration sampling not described.
	Baseline comparisons	None.
	Study sufficiently powered	No – statistical problems described in critique by Legg, Davies and Gray*.
Outcomes and methods of analysis (inc effect size, CIs for each outcome and significance)	Primary outcome measures	Biomass of above and below ground matter. Biomass removed by burning. Soil carbon storage (to 0.3m) and soil respiration.
	Secondary outcome measures	Estimates of carbon storage in above and below ground biomass.
	Follow-up periods	n/a
	Methods of analysis	Statistical analyses not described.
Results		Soil carbon stored in above ground biomass ranged from 600 – 1325 g C m-2 which is greater than the approx.200 g C m-2 assumed for heaths in the UK carbon inventory.

		16 and 24 % of above ground biomass was removed by burning in fires sampled over two years with direct releases of 103 and 201 g C m-2. Indirect carbon losses were estimated to release another 5-21 g C m-2 yr. The overall carbon losses from burning are ,10% vof total losses of carbon from the system. The carbon budget for this moor is in the range 34g C m-2 net loss to 146 g C yr m-2 net gain.
Notes	Limitations identified by author	
	Limitations identified by review team	Severe reservations as presented by Legg et al * relating to sampling procedures and analyses. Data seem anomalous and difficult to explain – sources of variation between sample sites have not been eliminated or accounted for so could explain the results. Sample sizes are small and sampling protocols and rationale not fully explained.
	Evidence gaps and/or recommendations for further research	
	Sources of funding	Not reported.

*Legg, C, Davies, GM & Gray, A (2010) Comment on ‘Burning management and carbon sequestration of upland heather moorland in the UK. Australian Journal of Soil Research, 48, 100-103.

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)

Study details	Authors	Fletcher *et al*. [Also GWCT 2010 booklet on the results.]
	Year	2010
	Aim of study	Investigation of the impact of predation on upland breeding birds in an eight-year field experiment in which the abundance of legally controllable predators was manipulated whilst maintaining consistent habitat conditions. This was carried out at four moorland/marginal farmland study sites in Northumberland. Numbers of seven ground nesting bird species were monitored and breeding success of five of them. Sites were paired, one with predator control and the other none, and control was switched halfway through.
	Study design	1: controlled, large-scale experiment. Could be regarded as case-studies.
	Quality score	1+
	External validity	EV+
Population and setting	Source population	Northumberland moorland and moorland fringe.
	Eligible population	Two sites

	Inclusion and exclusion criteria	NA
	Setting	Four moorland/moorland fringe sites (9-14 km^2) in Northumberland.
Methods of allocation to intervention/control	Methods of allocation	
	Intervention description	Legal predator control of fox, stoat, weasel and corvids.
	Control/comparison description	One site with no control paired with another with control over the seven-year period. In the second pair, treatments (PC and no PC) switched half way through.
	Sample sizes	Four sites.
	Baseline comparisons	NA. Sites under different treatments or switched between predator control and no control, and differences in breeding numbers and success compared.
	Study sufficiently powered	NR, but small sample.
Outcomes and methods of analysis (inc effect size, CIs for each outcome and significance)	Primary outcome measures	Breeding numbers and success.
	Secondary outcome measures	Predator numbers.
	Follow-up periods	Seven years (plus initial baseline year).
	Methods of analysis	GLM.
Results		Control was successful in decreasing the abundance of fox *Vulpes vulpes* (-43%) and carrion crow *Corvus corone* (-78%). These reductions lead to a threefold increase in breeding success of

		lapwing, golden plover, curlew, red grouse and meadow pipit. This resulted in a subsequent increase in breeding numbers of these species apart from meadow pipit. As would be expected, this suggests that some of the increases seen in some species on grouse moors in other studies reflect predator control rather than just burning.
Notes	Limitations identified by author	NR
	Limitations identified by review team	Not directly related to burning, but of relevance re. consideration of the balance of effect between the gamekeepering activities of burning and predator control. Small sample size. Restricted to only seven species; effects on other breeding birds should be considered especially as the two passerines showed some different responses. Some of the changes in numbers were relatively small (and expressed as percentage change) especially given the relatively high level of intervention. There were differences in breeding numbers between sites with the no-PC site starting with and maintaining the lowest numbers. Predator control on adjacent land NR.
	Evidence gaps and/or recommendations for further research	See above.
	Sources of funding	GWCT.

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) What are the effects of managed burning on the maintenance and restoration of the characteristic floristic composition, structure and function of upland peatland habitats? b) What are the effects of managed burning of upland peatlands on carbon sequestration and storage, either directly or indirectly through changes in vegetation composition and structure?

Study details	Authors	Forrest, G.J. & Smith, R.A.H.
	Year	1975
	Aim of study	(A) To estimate the variation in annual production on a range of blanket bog types with the Moor House NNR and determine whether this was related to management heterogeneity which resulted from variation in microhabitat and management factors. (B) To determine whether productivity varied between year by obtaining limited data from one site over a three-year period. (C) NB although plant frequencies of sample plots are detailed for burnt and unburnt sites, this was provided purely as description of the study sites. The detailed methodology for the plant frequency data is not provided. Note the data were analysed in the systematic review by Stewart et al. 2004.
	Study design	Observation/Correlation

	Quality score	2-
	External validity	EV-
Population and setting	Source population	Upland blanket bog
	Eligible population	Principally *Calluna-Eriophorum* blanket mire between 515 and 561m altitude.
	Inclusion and exclusion criteria	All sites within 1km of each other, peat depth 1.2-4m.
	Setting	Moorhouse NNR, N Pennines
Methods of allocation to intervention/control	Methods of allocation	2 sites burnt in 1961 (studies carried out 1969-1971
	Intervention description	Managed burning c. 9 years previous – no details of intensity, return time, burn area
	Control/comparison description	2 burnt sites = Cottage Hill A and Cottage Hill B. Cottage Hill A is also the wettest site while Cottage Hill B is the third wettest of the 7 sites examined.
	Sample sizes	7 sites (2 burnt, 5 unburnt). Plant frequencies determined from 50 25cm square quadrats from each site.
	Baseline comparisons	No baseline data from two burnt sites prior to burning.
	Study sufficiently powered	Probably not due to the small number of burnt sites. No power analysis.
Outcomes and methods of analysis (inc effect size, CIs for each	Primary outcome measures	Total (above and below ground) and component net production.

outcome and significance)	Secondary outcome measures	Floristic composition (frequency of species) – not analysed but reported.
	Follow-up periods	No follow up but study took place c. 9 years following burn.
	Methods of analysis	ANOVA
Results		Between year variation in total production was relatively small compared to that between sites. Mean total (above and below ground) production was highest on the burnt sites (805 +/- 64 g m^{-2} y^{-1}) than on the unburnt Calluneto-Eriophoretum (629 +/- 54 g m^{-2} y^{-1}) and Trichophoro- Eriophoretum (491 g m^{-2} y^{-1}) sites. The authors report that it is likely that the total production of the vegetation at the previously burnt site Cottage Hill B (868 g m^{-2} y^{-1}) was significantly greater than one of the non-burnt site Green Burn (491 g m^{-2} y^{-1}). It is also likely that there were no significant differences between remaining sites although the other burnt site, Cottage Hill A, was also high (741 g m^{-2} $y^{-1.}$). Authors note that high productivity of Cottage Hill sites result largely from presence of E*. angustifolium* and/or *Trichophorum cespitosum* which probably have high relative growth rates, combined with the juvenile nature of the vegetation due to burning. Since the two Cottage Hill sites were so wet which is likely to influence baseline floristic composition, it is not clear to what extent the high production on these burnt sites is due to burning vs difference in baseline community types. For the unburnt Calluneto-Eriophoretum and Trichophoro- Eriophoretum sites there was a significant trend of decreasing production with increasing wetness (primarily due to decreasing production of *Calluna* and *E. vaginatum*, only partly compensated for my increasing production of *Sphagnum*). The study was not designed to examine changes in floristic composition resulting from burning but since species frequencies were reported, comparison of burnt and unburnt sites is possible. However since the burnt sites were generally wetter than non-burnt

		sites (wettest and third wettest of 7 sites), the effect of burning is confounded by wetness. The two burnt sites had higher frequencies (no statistical tests carried out) of a number of species, including *Eriophorum angustifolium, Trichophorum cespitosum, and Narcthecium ossifragum,* together with a number of Sphagnum species, while the frequency of some species, such as *Empetrum nigrum* and the lichens *Parmelia saxatilis* and *Cladonia squamosa,* were lower. The low standing crops at Cottage Hills B of all *Calluna* components considered to be a result of the juvenile state of plants following the recent burn.
Notes	Limitations identified by author	Changes in methodology from year to year
	Limitations identified by review team	In relation to the review question, the study is limited by the fact that the comparison of burn/non-burn sites is confounded by wetness and lack of baseline vegetation community data. Thus it is not clear the extent to which the differences in productivity and floral composition are a result of burning. The two burnt sites also had much deeper peat than most of the other sites surveyed.
	Evidence gaps and/or recommendations for further research	Clarification of whether there are any baseline data on the floristic composition/vegetation communities of the burnt sites (prior to burning) could help validate this study.
	Sources of funding	?

Forrest, G.I. (1971) Struction and production of north Pennine blanket-bog vegetation. Journal of Ecology 59: 453-479

This paper is referred to in the above study. This paper describes one study site. Forrest and Smith (1975) extended the study to 6 additional study sites using same methodology.

Forrest (1971) examined the production of the dwarf shrub-tussock community, dominated by *Calluna vulgaris* and *Eriophorum vaginatum*, at a site (Sike Hill) in the Moor House NNR, North Pennines. The site had not been burnt since 1938 and was only lightly grazed with sheep (0.13 sheep/ha). Total community production was 635 g m^{-2} y^{-1}, higher that grasslands on the Moor House Reserve at comparable altitude. The production of *Eriophorum* was particularly high (annual turnover of nearly 50% of the summer biomass) and lichens the lowest. The community considered to be in steady state and the reasons for this are discussed (primarily losses by desiccation under certain winter weather conditions and the blockage of older stems by heartwood).

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) carbon

Study details	Authors	FULLEN, M.A.
	Year	1983
	Aim of study	An assessment of the effects of heather removal by burning on moorland air temperatures and wind velocities at a *Calluna-dominated site on peat* in the North York Moors. Temperature and wind velocity were recorded above a mature (37 cm tall) *Calluna* stand and above the surface of a recently burnt (in April 1978) *Calluna* stand. Temperature was recorded using an automatic recorder between September 1978 and August 1979 (348 days) and wind velocity measurements were taken over an eight-hour period in June 1980.
	Study design	3: case-study
	Quality score	3+
	External validity	EV-
Population and setting	Source population	North York Moors *Calluna*-dominated moorland (including on peat).

	Eligible population	Burnt and unburnt *Calluna* stands on one site in the North York Moors.
	Inclusion and exclusion criteria	NR
	Setting	Egton High Moor (*Calluna*-dominated vegetation on deep peat), North York Moors.
Methods of allocation to intervention/control	Methods of allocation	NA. Burnt and unburnt stands selected for measuring temperature and wind velocity.
	Intervention description	Managed burning.
	Control/comparison description	Adjacent 'unburnt' stand.
	Sample sizes	348 days of temperature recording and 50 wind velocity profiles from an eight hr period in two stands on one site.
	Baseline comparisons	NA
	Study sufficiently powered	NA/NR, but a case-study.
Outcomes and methods of analysis (inc effect size, CIs for each outcome and significance)	Primary outcome measures	Air temperature at different heights (2 cm above the surface in the burnt stand and 37 cm in adjacent 15 yr old stand) with continuous recording between 1 September 1978 and 31 August 1979. Wind velocity at 9, 41 and 100 cm above the surface
	Secondary outcome measures	Daily max, min and mean temperature and max variation in temperature (max- mean). Vegetation biomass (air dry)/0.25 m^2. 50 wind velocity profiles for an 8 hr period.
	Follow-up periods	Up to 16 months after burn; 'unburnt' stand 15 yr.
	Methods of analysis	Student's t tests and Pearson correlation co-efficient.

Results		Temperatures above the burnt moor were extreme and variable at instantaneous, diurnal and seasonal timescales. Differences in daily maximum temperature, daily minimum temperature, daily maximum temperature variation, daily duration of sub-zero temperatures and daily number of freeze-thaw cycles were all significant (p <0.001) as were differences in daily mean temperature (p <0.05). Temperatures were higher on the burnt stand during summer, but higher in the *Calluna* stand in winter). Burnt moorland was reported as being more susceptible to freezing temperatures and more prone to freeze thaw cycles (100 during the year *c.f.* 64 in the heather stand). *Calluna* stands act as a protective buffer against temperature extremes, removal of which exposes moorland to temperatures which may promote breaking and fragmentation of peat surfaces. Wind velocities at three heights above the burnt moorland were higher than above the heather stand. Wind velocity was significantly different from the *Calluna* stand (p <0.001) at both 9 cm and 41 cm above surface height (p >0.001), but not at 100 cm. The author suggested that these results will lead to enhanced development of desiccation crack, fragmentation of peat surfaces and therefore enhanced wind and water erosion.
Notes	Limitations identified by author	NR
	Limitations identified by review team	Small sample size; a single site case-study.
	Evidence gaps and/or recommendations for further research	Perhaps worth repeating on a range of sites with differing characteristics, eg aspect, exposure, vegetation type/height etc. Further work on link to erosion.
	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)	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	Garnett, M H, Ineson, P & Stevenson, A C
	Year	2000
	Aim of study	To determine whether sheep grazing and burning of moorland every 10 years influenced Carbon accumulation in peats.
	Study design	Experiment – using the Hard Hill experiment partially randomised control trial at Moor House NNR.
	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	Sampled plots subject to grazing + 10 year burn rotation, grazing + no burning and no grazing + no burning.
	Control/comparison description	No burning or grazing since 1954.
	Sample sizes	3 treatments x 4 plots each x 1 sample
	Baseline comparisons	n/a – no data about pre 1954 conditions (but reference to source paper).
	Study sufficiently powered	Small sample sizes.
Outcomes and methods of analysis (inc effect size, CIs for each outcome and significance)	Primary outcome measures	Depth of peat above a chronological marker from which mass of carbon is calculated.
	Secondary outcome measures	None.
	Follow-up periods	n/a
	Methods of analysis	Carbon estimated as 50% of dry mass. Results from samples tested by ANOVA.
Results		No differences in the accumulation of peat between grazed and ungrazed treatments were detected. This may be due to low sheep grazing rates. Significant differences in Carbon accumulation between the 10 year burn and no burn plots were found (3.1 +/- 0.4 Kg m-2 vs 5.4 +/- 0.6 Kg m-2). It is not possible to say

		whether this results from reducing the rate of accumulation and / or reducing carbon stores through burning accumulated peat. The differences in the treatment reflect the impact of burning over a 32 year period and the difference in Carbon sequestration in that period is of the order of 73 g m-2 yr-1
Notes	Limitations identified by author	Use of chronological marker to establish a baseline for comparison of accumulation rates – potential errors discussed and validated by examination of accumulation of charcoal particles (assumed to be locally derived e.g. from the 1954 fire). Grazing rates may be too low to detect an effect. Study cannot separate effects of burning effects on peat accumulation rate and burning existing peat.
	Limitations identified by review team	Small number of samples. No replication within sample plots. Study did not utilise intermediate burn treatment. Grazing rates are too low and are unreliable. Assumptions about the carbon content of peat not tested.
	Evidence gaps and/or recommendations for further research	Extend study to assess rates of peat accumulation elsewhere. Further palaeoecological study to identify 'signatures' of fire events in recent peat deposits to demonstrate cyclical (or not) effects of burning as seen in recent fires as measured by other studies (e.g. EMBER).
	Sources of funding	ITE, University of Newcastle, DOE

Evidence Table

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

Study details	Authors	Garnett, M.H., Ineson, P., Stevenson, A.C. & Howard, D.C.
	Year	2001
	Aim of study	To estimate accurately the size of the terrestrial carbon store in the vegetation and soil components of a British moorland.
	Study design	2: Carbon budget catchment study/correlation?
	Quality score	2++
	External validity	EV – does not directly address the question but may be important contributor via extrapolation
Population and setting	Source population	Moor House NNR, North Pennines
	Eligible population	22 x 1km^2 land units.
	Inclusion and exclusion criteria	1km^2 unit must be contained entirely within the NNR boundary

	Setting	Upland moorland comprising blanket mire and upland grassland.
Methods of allocation to intervention/control	Methods of allocation	None N/A
	Intervention description	None N/A
	Control/comparison description	Existing data on stored C content, essentially for soils from previous studies
	Sample sizes	Sample sizes only relevant to determination of soil C content; sample sizes proportional to representation of soil type within study site and dominated by peatland component.
	Baseline comparisons	Existing national inventory
	Study sufficiently powered	Statistical treatment only applies to determination of soil C content, which is recognised as under-powered for the least abundant soil types.
Outcomes and methods of analysis (inc effect size, CIs for each outcome and significance)	Primary outcome measures	2D area and true surface area for all vegetation types present. Above ground biomass & C content for all vegetation types present. 2D area for all soil types present C content for top 30cm, 50cm & 100cm soil for most of the soil types present
	Secondary outcome measures	Total C stored for all vegetation types present. C content for total depth of soil for all soil types present Total stored C for top 50cm, 100cm & total soil depth soil types present. Total stored C for individual 1km^2 units.
	Follow-up periods	N/A

	Methods of analysis	Scaling of primary outcomes according to area of each type present. Limited scope for statistical treatment of data.
Results		True surface area and 2D area essentially equivalent in this study. Vegetation less important than soil for C storage Peat soils, especially blanket bog, contain the greatest stored C. Stored C in vegetation similar to existing national inventory The study gave estimates of stored C for each 1km^2 unit >1/3 lower than the national inventory, attributed to higher resolution of determining soil C in the site-specific study, with fewer generalisations regarding the distribution of soil types. Available estimates of stored C should be viewed with caution because of the scale of inaccuracies that are possible
Notes	Limitations identified by author	Errors in original field survey data used to create digitised maps for determining surface area. Other inaccuracies/high variability limited to less widespread vegetation & soil types.
	Limitations identified by review team	Absolute values used throughout the scaling process, therefore only a single value of stored C is generated for each category of vegetation/soil. Not possible to determine the potential scale of variability as no ranges are presented other than for soils sampled specifically for the study.
	Evidence gaps and/or recommendations for further research	Variations in stored C content of vegetation are less important than those in soils. Future research should therefore concentrate on improved mapping and analysis of the latter to improve estimates both nationally and globally.
	Sources of funding	University of Newcastle-Upon-Tyne, ITE & UK DoE.

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

Study details	Authors	Grand-clement
	Year	2008
	Aim of study	T o assess the effects of burning in peatland environments on SOM and peat accumulation
	Study design	Quantitative experimental/correlation/carbon budget
	Quality score	2-
	External validity	EV-
Population and setting	Source population	UK upland peatland habitats
	Eligible population	Blanket bog vegetation – Calluna/Eriophorum/Sphagnum dominated (M19/20). >1 m peat depth.
	Inclusion and exclusion criteria	Management by burning
	Setting	N. England :

		Moorhouse-upper Teesdale NNR Howden Moor (Peak District)
Methods of allocation to intervention/control	Methods of allocation	Site selection – purposive, based on burn records
	Intervention description	Burning
	Control/comparison description	Site burnt the day before sampling compared with 5, 10 and 20 years prior to sampling/unburnt since 1954
	Sample sizes	Surface samples - 11 bulk sub-samples per plot Depth samples – N/R Peat cores – 1 core per plot
	Baseline comparisons	-
	Study sufficiently powered	Study not replicated
Outcomes and methods of analysis (inc effect size, CIs for each outcome and significance)	Primary outcome measures	soil organic matter composition peat accumulation rates
	Secondary outcome measures	Soil pH Moisture content Loss on ignition Total carbon Nitrogen

	Follow-up periods	Day after burning, 5, 10 and 20 years after burning
	Methods of analysis	Comparison of ^{13}C spectra Black carbon analysed by general linear regression and ANOVAs
Results		The method used in the present study (^{13}C NMR spectroscopy) showed no increase of aromatic structures in the bulk soil, either immediately after a burn, or in the case of longer fire rotations (i.e. every 10 or 20 years). The outcome of the burning experiment showed the charcoal particles do contain some aromatic C, and therefore are likely to benefit the soil eventually. However, the charcoal production seems low (i.e. <1 % of the biomass burnt), and on a spatial scale the carbon added to the soil is negligible (about 16 g C ha). The heating of the heather plant material in the furnace at moderate temperature (350°C) but for a long duration (1 h) produced relatively more aromatic C. It is therefore asserted that a longer exposure to heat during fire could increase the aromatic content in the burned residues. Results indicated that, if processes of organic matter modification occur, their impact remains negligible. Few changes were observed in black carbon quantities as a direct result of fire treatment. However, the soil still contains significant stocks of BC (e.g. between 1 and 1.4 T ha in the top 5 cm in the Peak District sites). Relatively high peat accumulation rates were measured (between 4.2 and 14.1 cm/yr) with a high variability between plots, the most frequently burnt plot having the fastest accumulation rate.
Notes	Limitations identified by author	Results obtained with NMR spectroscopy are semi-quantitative and their precision uncertain. Only one sample per treatment was analysed
	Limitations identified by review team	Lack of replication/single samples for peat cores
	Evidence gaps and/or recommendations for	The study only considered BC entering the soil, and not emissions into the atmosphere

	further research	
	Sources of funding	JNCC/SNH

Evidence Table

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

Study details	Authors	Grayson, R., Kay, P., Foulger, M. & Gledhill, S.
	Year	2012
	Aim of study	To construct a GIS based model to predict water colour generation in UK upland drinking water catchments
	Study design	Correlation - Model
	Quality score	2+
	External validity	EV+
Population and setting	Source population	Souther Pennines & Peak District
	Eligible population	Eastern flank catchments feeding drinking water reservoirs
	Inclusion and exclusion criteria	Available water colour data must relate to a known catchment Monitoring location must not be affected by other raw water inputs Data set must be of adequate resolution (1995-2006 and monitored at sufficient

		frequency)
	Setting	Yorkshire (data sets acquired from Yorkshire Water)
Methods of allocation to intervention/control	Methods of allocation	**Interpreted as the process by which parameters were selected for defining GIS cells** Determination of valid parameters was achieved via extensive literature search and evidence gathering (not presented as rigorous evidence base however) Standard databases used for landcover (ITE 1990 – dated) Digital Terrain Map NATMAP for soils BSG for geology Aerial photographs (2000 – i.e. mid data period) for burnt area, grips & afforestation & validated by field survey
	Intervention description	**Interpreted as the definition of parameters for defining GIS cells** Selection of variables of known (if mostly correlative) propensity to generate water colour based on literature: Landcover type, slope, aspect, topographic index, soil type, underlying geology, grips, natural hydrology (existing runs/channels), burnt area, area and type of afforestation, land tenancy (water company versus other)
	Control/comparison description	Multi-criteria evaluation model based on simple additive weighting (SAW) of parameters: comparisons arise from the range of states that are possible for these parameters, which can be binary or quantitative.
	Sample sizes	18 catchments submitted to the model using a rationalised subset of 8 parameters

	Baseline comparisons	Baseline comparisons in the context of the model are the precision of the statistical relationships that exist between the empirical values of each parameter and mean water colour for the catchment. The precision of the final relationship between rescaled parameters should be equivalent in magnitude in order to validate the standardisation process.
	Study sufficiently powered	The final model predicts ca. 90% of the variation in historic mean water colour among the catchments, R^2 = 0.886 (p<0.01)
Outcomes and methods of analysis (inc effect size, CIs for each outcome and significance)	Primary outcome measures	Primary outcome measures are: Topographic index for determining grip effects based on the effects on water table and topography, derived initially from digitised aerial photographs Rescaled and weighted values of each model parameter, which are entered into each GIS cell
	Secondary outcome measures	Secondary outcomes, in model process order: the rescaled and reweighted parameter values total cumulative score for each GIS cell total cumulative score for all cells in a catchment
	Follow-up periods	Water colour data sets span 1995-2006
	Methods of analysis	Multi-criteria evaluation (MCE) including spatial multiattribute decision making (MADM) via simple additive weighting (SAW) Pearson correlation
Results		Standardisation via rescaling and weighting had negligible effect on the significance of

		the relationship between individual parameters and water colour concentration Most significant factors were heather burning and vegetation type. Afforestation, precipitation, slope, aspect and tenancy were unimportant in determining water discolouration. Water catchments with >40% of land surface burnt had the highest colouration Water colour was statistically +ively correlated to dense shrub moor (R^2=0.46 $p<0.01$: removal of 1 outlier improved this to R^2=0.641 $p<0.001$)) and a significant –ive relationship with moorland grass (R^2=0.24 $p<0.05$). Grip densities were low (<0.5km grip/km^2) in all but 2 catchments; where grip densities were higher inclusion of gripping in the model improved its fit. Only catchments with significant peat generate water colour but variation in the actual proportion of peat do not explain differences in water colour concentration. Data for the upper part of the Nidd catchment were used to validate the model. The predicted water colour concentration was 96.6 mgl^{-1}PtCo and the historic mean (1997 to 2007) was 96.4 mgl^{-1}PtCo. Model predicts hot spots within catchments can be used to produce colour hazard maps whereby remedial land management may be targeted.
Notes	Limitations identified by author	Parameters deemed of low importance for the 18 catchments used to construct the model may be important elsewhere if they are more prevalent (e.g. areas with high densities of grips, catchments that vary more in aspect)
	Limitations identified by review team	No recognition of the extent of the potential discrepancy in the relationship between measured water colour and DOC. Justification of the choice of parameters would have been strengthened by an evidence-

		based summary table rather than references alone.
	Evidence gaps and/or recommendations for further research	Explore the use of the model across a wider geographic area, e.g. south west uplands
	Sources of funding	Not acknowledged – presumed to be Yorkshire Water