

Burning on Deep Peat and Bog habitat in England

Reconciliation and re-examination of results from English Nature

Research Reports 667, 698 and unpublished data

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Executive Summary

The 'Heather and grass burning code' recommends a strong presumption against burning on bog and blanket peat without the agreement of Natural England. Burning on SSSIs also requires consent from Natural England. There is however no systematic monitoring of burning in these habitats and therefore no measure of how effective current voluntary and designated site controls are.

A reconciliation and re-analysis of digital datasets of moorland burning has been used to provide estimates of the extent of managed burning in blanket bog habitat and blanket peat soil in England for the first time.

Of all burning nationally, some 40% occurs on blanket bog; in the North Pennines AONB, this rises to c.60%. In many regions burning is more intense on SSSIs than elsewhere. In the North Pennines, for example, some 6.9% of heather-dominated SSSI on deep peat is burnt annually, compared to 5.8% of non-SSSI. In the North York Moors, some 8.5% of heather-dominated SSSI on deep peat is burnt annually, i.e. a repeat time of <12 years.

It has been estimated that some 114 km² of new moorland burns occur annually (at yr 2000). The figures here indicate that this partly comprises between 44-54 km² of new burn on bog, and between 52-69 km² on blanket peat, each year. *There is therefore effectively no*

difference between the intensity of burning on bog or deep peat habitat and upland heathland. From this it is apparent that the voluntary code, Natural England management agreements, and site designation are having little demonstrable effect in protecting either bog or blanket peat areas from fire use.

Upland blanket peats are ultimately derived from bog habitat. However, nearly half (1197 km²) of the total (2902 km²) of blanket peat in England is currently overlain by habitat not regarded as bog. *That nearly half of this resource is already degraded enough to no longer be classified as bog habitat almost certainly indicates a significant compromising of biodiversity and the ecosystem services, in particular carbon sequestration, these areas are usually presumed to provide.*

1 Introduction

1.1. Background

There is currently much debate about the potentially damaging impact of burning on the biodiversity, nature conservation interest and wider ecosystem services of blanket bog and degraded blanket bog habitat (for reviews see: Tucker, 2003; Stewart *et al.*, 2004; Worrall *et al.*, 2011; IUCN, 2011). Concerns about the possible adverse effects of burning on bog habitats on blanket peat are manifest within the revised Defra guidance, 'The Heather and Grass Burning Code' (issued previously by MAFF in 1992 and republished in slightly amended form 1994; revised as Defra, 2007). The 1992 version baldly states "Do not burn: Peat bog and wet moor (flow ground)" whilst this was revised in the 2007 version by the inclusion of "peat bog and wet heathland" in the list of sensitive areas where there "should be a strong presumption against burning". However, the 2007 version goes on to say that: "These areas (including blanket bogs, raised bogs, valley bogs or mires, springs and flushes) should not be burned other than in line with a management plan agreed with Natural England. Such plans are likely to involve careful burning on long rotations, with cool burns leaving large amounts of "stick" and not damaging the moss layer." Hitherto however, there have been few data to establish to what extent bog habitat, including that with protected status within SSSI, is being burned. We therefore have no measure of the effectiveness of current voluntary Code and/or site designation.

The national extent and importance of management burning within ericaceous dominated habitat has been noted previously (Yallop *et al.*, 2006a). However, this study made no

attempt to differentiate bog from heath habitat and could not therefore provide information as to the extent of burning occurring within bog areas. In a further study encompassing the North Pennines AONB, Yallop *et al.* (2006b) reported on the intensity of burning within areas of upland heath and bog habitat defined by English Nature (now Natural England) and within SSSIs. Soil data were not included in this study, however, so again there was no opportunity to distinguish sites that are on deep/blanket peats and should therefore be regarded as bog.

1.2. Managed burning in the English uplands

The use of fire in the English uplands has an informal history of thousands of years with a more ‘organized’ adoption of its use dating from the mid- to late- nineteenth century. Burning of dwarf-shrub heath-dominated habitats (DSH: primarily heather *Calluna vulgaris*) removes woody material and litter, and promotes a flush of new growth from rhizomes or stem bases, thus improving grazing for stock. Heather is also an important food for red grouse *Lagopus lagopus scoticus*, so providing areas of pioneer heather may help increase its population density. The mosaic structure of different-aged stands of heather may also benefit grouse by providing more niches for invertebrates, upon which grouse also feed, and by providing cover and nesting sites. Today the single biggest reason for moorland burning in England is management for red grouse shooting.

1.3. Ecological effects of burning blanket bogs/deep peat soils

Well-managed burning on upland heath contributes to a mosaic of different seral stages of heather growth that is known to benefit other wildlife and plants, as well as red grouse. The effect of burning vegetation on blanket bog, however, is both contentious and under-researched (Glaves & Haycock, 2005), and it is debatable whether vegetation on bogs should be burned at any time. Recognition of this is explicit in the Heather and Grass Burning Code (Defra, 2007) which proscribes burning on such habitat without consent from Natural England. The present balance of evidence points to burning of vegetation on bog being detrimental for biodiversity conservation interests (Shaw *et al.*, 1996; Tucker, 2003; Stewart *et al.*, 2004; IUCN, 2011). In addition there is now considerable evidence that surface waters draining catchments with a higher intensity of new moorland burns on blanket peat are more highly coloured and export larger amounts of dissolved organic carbon (Yallop *et al.*, 2008; Yallop & Clutterbuck, 2009). Areas of blanket peat exposed by new burn release 5-15 times more carbon in this form compared to canopied areas (Yallop *et al.* 2010). This phenomenon appears to underlie a large proportion of the increases in humic coloured DOC

export from peat catchments observed over the recent past (Clutterbuck & Yallop, 2010).

Most British blanket bogs are heavily modified by management (c.18,500 km² of 22,500 km²) according to an estimate by Bragg & Tallis (2001); according to Natural England (2010), “Only 1% of England’s deep peats have been mapped as being in an undamaged state where they remain substantially waterlogged and actively continue to form peat and therefore sequester carbon.” Blanket bog is a UK BAP priority habitat and active blanket bog is a priority habitat under the EC Habitats Directive. It is likely that the formation of bogs occurred under a low-grazing, infrequent wildfire regime. Pollen studies have shown that bog mosses *Sphagnum* spp. can re-establish after burning in the absence of other impacts (Pitkänen *et al.*, 1999), although high-frequency burning may reduce or stop peat formation (e.g. Garnett *et al.*, 2000). Wieder *et al.* (2009) found that bogs in Alberta, Canada represent a net carbon source for 13 years after a fire, and become a net sink after that time. Zero net accumulation of carbon would occur with return times (i.e. fire frequencies) of 61 years or less in their study.

1.4. Scope and constraints of the project

The aim of this project is to review currently available moorland burn mapping data to measure the extent of this fire management on upland bog habitat in England. Such an exercise requires digital mapping of this habitat, of which currently the only suitable source is Natural England's blanket bog habitat inventory version 2.1. It should be noted that the authors of this report have previously observed that there are constraints with regard to the accuracy and completeness of these data.

Firstly, although derived from a number of sources including Phase 1 and/or NVC field mapping and aerial imagery, these exercises are more likely to have been undertaken within SSSIs than elsewhere, and hence may under-record actual bog extent beyond these areas. This may partly account for the considerable differences in estimates of bog habitat between this source (some 2400 km²) and that reported by Natural England (2010), which suggests around 3500 km². The latter estimate is not available as part of digital inventory mapping and could not be utilised here. In addition there are numerous GIS topological and geometric errors in this vector dataset.

To achieve its aim this project combines and reanalyses, where required, the data collated and presented in:

- 1: Yallop *et al.*, 2005 (A History of Burning as a Management Tool in the English Uplands. English Nature Research Report 667) which assessed the extent of management burning within England by a sample approach using digitisation of burn parcels;
- 2: Yallop *et al.*, 2006b (Mapping Extent of Burn Management in the North Pennines: Review of extent Yr. 2001-2003. EN Report 698) which mapped burning across the entirety of the North Pennines AONB using an image sampling approach;
- 3: Currently unpublished NE data that mapped new moorland burning within the entirety of both the Peak District National Park (NP) in 2005 and North York Moors NP in 2009 using image segmentation techniques on 4-band digital aerial imagery acquired by ADS40 sensors.

As outlined above, although 'bog' habitat is defined as occurring on deep peat soils, there is some disagreement between deep peat and blanket bog datasets. We have chosen to present an analysis using two ways of defining 'bog', to overcome, as far as possible, issues regarding the incompleteness of habitat mapping. The estimates in this report have therefore been derived from the identification of burning that occurs:

- i. on upland blanket or deep peat soils to identify areas where blanket bog either occurs or formerly occurred, i.e. where characteristic bog habitat defining species may currently be absent. This was undertaken using digital soil mapping data from the National Soil Resource Institute (NSRI) and provides a good surrogate for extant and past bog extent.
- ii. in areas mapped within Natural England's digital blanket bog habitat inventory (NE blanket bog habitat mask v2.1).

In addition, as burning is expected to occur mainly in habitat defined as upland heath, comparison is made between these two habitats, where upland heath is defined in NE upland heath habitat digital mapping v2.1.

Constraints

It must be accepted that the errors observed in the digital habitat inventories, for example habitat overlap, as well as GIS geometry errors, will affect all estimates reported by habitat here. As no accuracy assessments are provided with these NE digital data (in itself a peculiar omission) it is impossible to quantify the accuracy margins for the estimates produced here. They will simply serve therefore as a 'best' estimate for burning practices in these habitats.

It should also be noted that all upland blanket and deep peat soils from the NSRI soil inventory include areas of peat that have now been developed into other land uses (e.g. forestry or peat extraction), and are therefore not considered suitable for burning management. Thus statistics provided here reporting burn management as a percentage of the total extent of deep peat soils will underestimate intensity.

Perhaps the primary limitation or constraint to the reporting here is however that the data used for the national analysis are now well out of date being based upon imagery from the yr 2000. It is known that in many areas burning has increased markedly since then (Clutterbuck & Yallop, 2010; unpublished NE data) so the estimates are likely to significantly underestimate any possible impacts.

2. Methods

2.1. Data

2.1.1 Data on burning in the English uplands

National sample

Evidence of burning from a random sample of aerial photography (dating from the year 2000) of the English uplands consisting of 208 1 km² tiles was collected in an earlier study for English Nature (Yallop *et al.*, 2005). These digitized sample squares were re-sampled using a systematic sampling grid (841 points per km²) and classified into one of the five original categories. Details of the categories used in the aerial photographic interpretation (API) can be found in Yallop *et al.* (2006a) and Yallop *et al.* (2006b), but are summarised below for clarity.

0: No visual presence of ericaceous shrub

Habitat unlikely to be managed by burning e.g. Eriophorum dominated bog/moor. This class will include all agricultural activity and other habitat/land cover types spuriously included in the EN digital data should they occur.

- 1: New burn – *within approx. 0-5 years***
- 2: Recent burn – *within approx. 4-8 years***
- 3: Visually closed canopy – *estimated age 7-15 years***
- 4: Mature, degenerate DSH – *greater than 15-25 years or unmanaged***

The 208 squares include 40.8 km² of upland heath and 50.8 km² of bog habitat, representing samples of 1.8% and 2.1% of the national resource included in the Natural England habitat inventories respectively. The sampled area covers 60.7 km² of deep peat, or 2.1% of the national total.

North Pennines AONB

Details of the original sampled area and protocol can be found in Yallop *et al.* (2006b). The sampled area assessed here has now been extended to include all areas of deep peat and ericaceous dominated vegetation on all soils that lie outside the extent of NE upland bog and heath habitats within the AONB. The aerial photography used was taken between 2001 and 2003. Sample points at the same density as in the national sample above were classified into the same five categories. From the total area of the AONB (1985 km²), the sampled area contains 640.9 km² (26.2%) of English blanket bog and 344.7 km² (15.2%) of English upland heath. The area also contains 746.3 km² (25.7%) of the land surface in England covered by deep peat.

Peak District (2005) and North York Moors (2009) National Parks

The full area of each park was mapped from 25 cm resolution 4-band digital ortho-rectified imagery. With reference to historical imagery for each park, new burns (typically <3 yrs old) were identified using automated image segmentation and classification procedures. The Peak District NP contains 230.3 km² (9.4%) of English blanket bog, 178.0 km² (7.9%) of upland heath and 256.1 km² (8.8%) of blanket peat. The NYM NP contains 19.8 km² (0.8%) of English blanket bog, 430.7 km² (19.0%) of upland heath and 41.5 km² (1.4%) of blanket peat.

Reconciliation

There were differences in the reported duration or period of mapped burns in some studies compared to others. For example data for the North Pennines AONB reported all burns of

<7.7 yrs owing to difficulties in differentiating between Class 1 (no visible regenerating *Calluna*) and Class 2 (partial canopy of regenerating *Calluna*) because of poor quality imagery, whereas the higher quality imagery available for the Peak District and NYM allowed burns less than 3 yrs old to be identified and mapped.

To allow valid comparisons to be made between different areas, all extents of burn mapping have therefore been summarized as annualised rates.

2.1.2 Soil data

Soil data were obtained from the digital soil map created by the National Soil Resource Institute (NSRI) as this currently represents the most comprehensive national dataset of soil type. The soil series 1011a, 1011b, 1013a and 1013b (deep and blanket peats) were extracted from this dataset and used for this analysis.

2.1.3 Habitat data

Habitat data were taken from Natural England’s Blanket Bog v2.1 and Upland Heath v2.1 digital habitat inventory datasets. The total area of upland heath according to these data is 2,265 km² and the area of blanket bog is 2,442 km², although as already noted there is some overlap or 'double accounting' between these datasets. Not all habitat area classified as ‘bog’ is on deep peat and conversely some of what is classified as heath *is* on deep peat (Tables 1&2). There are obvious classification issues relating to the boundaries of and between these habitats. However, assuming that the peat was laid down during a phase of accumulation in a former bog, heathland on deep peat represents degraded bog (whether degraded by climatic influences, or anthropogenic influences such as drainage, overgrazing and repeated burning). As such it should be considered to be ‘recoverable’ as defined by Natural England (see Appendix 3 in: Defra review of the heather and grass burning regulations and code: Science panel assessment of the effects of burning on biodiversity, soils and hydrology (Glaves & Haycock, 2005)).

Table 1. Relationship between NSRI soil type and NE digital habitat data for the 208 national sample squares (km²). Relationship with heather dominated proportion of NE habitats (derived from aerial photography) also shown.

	Heath	Total area		Heather dominated area	
		Bog	Heath	Bog	other
<i>Deep peat</i>	8.3	42.0	6.9	18.3	0.9

<i>Other soils</i>	32.5	8.8	20.4	2.6	5.3
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Table 2. Relationship between NSRI soil type and NE digital habitat data for the North Pennines AONB, Peak District and NYM National Parks (km²). Relationship with heather dominated proportion of NE habitats also shown.

	Total area			Heather dominated area	
	Heath	Bog	Heath	Bog	other
North Pennines					
<i>Deep peat</i>	101.9	546.2	66.9	218.5	10.9
<i>Other soils</i>	242.9	94.7	132.9	26.5	9.5
Peak District					
<i>Deep peat</i>	37.6	200.8	22.7	70.2	1.3
<i>Other soils</i>	140.4	29.5	58.2	8.7	5.2
NYM					
<i>Deep peat</i>	35.0	6.6	32.3	5.7	0.6
<i>Other soils</i>	395.7	13.2	280.6	5.2	6.7

2.2 Estimates of burning extent

There are two ways to interpret the extent of burning on deep peat soils and bog habitat. First, it is possible to assess the extent of recent burning of these habitats, as a measure of how they are affected by current practice. As burning is likely to have adverse effects on bog habitat, this measure may be considered an indicator of the current ‘health’ of these environments. Second, it is possible to assess what *proportion of the total moorland burning occurs on deep peat and bog habitat*. As this activity is not recommended within the Defra code, or requires consent, this is a measure of compliance with that code. As each approach reveals differing information regarding the burning of bog and deep peat habitats, both have been presented here.

2.3 Calculating repeat times

A repeat time is simply the time taken for an entire area to be burned. It can be calculated easily if a known proportion of the area in question has been burned within a known time period, which in this case is the time taken for burn scars to move into class 3 (see 2.1.1).

where $D_1 + D_2$ is the median time taken for burn scars to become class 3 and

$C_1 + C_2$ is their combined area.

The value of D_1+D_2 used here has been established observationally over a number of catchments (Yallop *et al.*, 2006a) and represents a ‘best guess’. Nevertheless, there is the possibility of variation in this figure, whether due to local differences in vegetation recovery or differences in quality of aerial photography. Taken on a broad scale, such a figure is an estimate only, since it obscures spatial variation in the intensity of burning. Also, it should be noted that repeat time figures are “exact” where closely dated (i.e. within the minimum time for a burn to move into class 3) photography is available. The equation above is only needed when a “snapshot” of an area is taken (as, e.g., for the North Pennines). For the Peak District and North York Moors, there is no uncertainty over the proportion of recent burn, because all burns were dated to <3 years old by the analysis of earlier photography.

2.4 Reporting statistics

Both bog and upland heath are composed of many differing community types, from monocotyledonous dominated areas intergrading into zones of ericaceous dominated habitat, which in managed areas will very often comprise a dominance of *Calluna vulgaris*. Only a proportion of both upland heath and blanket bog habitats identified by NE inventories (Tables 1 & 2) will therefore be considered worthwhile for fire management. The intensity of burning estimated using the full extent of each habitat will therefore be significantly lower than the intensity of burning estimated using solely the heather-dominated fraction. It is not considered feasible to produce accurate estimates of burning in non-ericaceous areas. This is because burning in such communities is generally only transiently visible in aerial photography. The extent to which this occurs is therefore unknown. Figures for burning intensity are given both with respect to ericaceous-dominated communities and for the habitats as a whole, even though all mapped burning is within the ericaceous-dominated areas.

It should also be noted that to address the aim of this report to produce national estimates the data presented will conceal much spatial variability in burning intensity. Average figures for both England and National Parks/AONB will therefore not inform local areas where management burning may be much lower or higher.

3 Results

3.1 Comparison of estimates of area of bog, upland heath, and deep peat habitat.

The differing estimates of bog habitat in England, as surveyed habitat from Natural England

data or implicit within soil NSRI data are summarised in Table 3. This shows that 1197 km² (41%) of blanket peat is currently overlain by habitat not defined as bog. Only 275 km² (9%) of this is defined as upland heath. Some 737 km² (30%) of blanket bog is present on non blanket peat soils.

	Upland heath (NE)	Blanket bog (NE)	Other heather moor	Deep peat (NSRI)
Total area	2265	2442	300	2902
On deep peat	275	1705	35	
On other soil	1990	737	265	

NE: Upland Heath and Bog digital inventory data

NSRI: National Soil Resource Institute digital soil map data

3.2 Extent of bog, upland heath, and deep peat habitat burned: National estimates

It should be noted that these national figures are based on imagery from yr. 2000 and a 2% sample. Of the 208 km² squares in this national sample, some 90.2 km² is classified as bog or heath (or both). Signs of recent burning were found on 16.5% of this area, with upland heath being slightly more intensively managed than bog. Based on the observation that class 2 burns remain visible for *c.* 7.7 years following a fire (Yallop *et al.* 2006a) this equates to annual burn rate of 4.5% and 3.8% of the *Calluna* dominated areas of upland heath and bog respectively. Full figures are reported in Table 4. Note that repeat time is derived by simple division of area by annual burn i.e. it assumes a consistency of management which is unlikely to be the case.

	Heather dominated area		Total extent of NE habitat	
	Upland heath	Blanket bog	Upland heath	Blanket bog
Annual burn %	4.5	3.8	3.0	1.5
Repeat time * (yrs)	22.3	26.5	33.6	64.7

* repeat times assume the entire area of the habitat is under the same management, though this is not likely to be the case.

Some 35% of the sample squares by area are within SSSIs so it is possible to examine the effect of statutory protection on burning management. Table 5 shows that both SSSI bog and upland heath have more intense burning regimes than non-designated sites.

Table 5. National estimates of management burning on SSSI and non-SSSI sites by habitat. (Figures as at year 2000.)

	SSSI		Non SSSI	
	UH	Bog	UH	Bog
Heather dominated area				
Annual burn %	4.9	4.0	3.3	3.3
Repeat (yrs)	20.5	25.3	30.3	30.4
Total extent of NE habitat				
Annual burn %	3.7	1.8	1.7	1.1
Repeat (yrs)	27.2	55.9	59.5	92.5

The more intense burning regimes observed in SSSIs are also visible when the data are examined by soil type rather than by habitat. Table 6 shows the annual average figures for both designated and non-designated sites.

Table 6. National estimates of management burning on blanket peat and other soils within SSSI and non-SSSI sites. (Figures as at year 2000).
n.b. 'other' includes shallow peat and peat- topped soils

	All England		SSSI		Non SSSI	
	B Peat	Other	B Peat	Other	B Peat	Other
Heather dominated area						
Annual burn %	3.7	4.0	3.8	5.2	3.5	2.4
Repeat (yrs)	27.1	25.0	26.6	19.4	28.8	41.8
Total extent of soil type						
Annual burn %	1.5	0.7	2.0	2.2	0.8	0.2
Repeat (yrs)	64.8	138.9	49.6	45.7	119.5	416.9

It is not clear why this should be so, at least for blanket bog/peat, as it would be expected that SSSI designation would provide some protection against what is seen as a damaging activity under national burning guidelines.

3.3 Burning on bog, heath, and deep peat in the North Pennines AONB and Peak District and North York Moors National Parks

Of the 936 km² of blanket bog or upland heath in the North Pennines AONB, some 22%

showed evidence of burning within the past 7.7 years. For these habitats in the Peak District (408 km²) and North York Moors (451 km²), 4.8% and 16.2% respectively of upland heath or bog were burnt within the previous three years.

Annualised burn rates indicate that levels of burning on bog habitat (as a proportion of *Calluna* present in each habitat class) are in fact higher than in upland heath habitat in both the North Pennines AONB and the North York Moors. In the Peak District less bog than upland heath is burned but the difference is very small. These figures are surprising considering the putative restriction of burning in such habitat.

Table 7. Estimates of burning on bog and heath in the North Pennines, Peak District and North York Moors

	Heather dominated area		Total extent of NE habitat	
	Upland heath	Blanket bog	Upland heath	Blanket bog
<i>North Pennines</i> ¹				
Annual burn %	6.2	6.7	3.6	2.5
Repeat time * (yrs)	16.1	15.0	27.8	39.3
<i>Peak District</i> ²				
Annual burn %	4.2	4.0	1.9	1.4
Repeat time * (yrs)	23.6	25.0	51.9	73.1
<i>NYM</i> ³				
Annual burn %	7.5	8.5	5.4	4.7
Repeat time * (yrs)	13.4	11.7	18.5	21.2

¹ based on yr. 2001/2003 imagery ² based on yr. 2005 ³ based on yr. 2009

Much of the heather-dominated areas of the North Pennines, the Peak District and North York Moors National Parks are protected as SSSI (c. 75%, 89% and 99% respectively). Data on burning in these areas, therefore, carries important information on burning management within SSSIs. Table 8 shows that, as with the data from the national sample, North Pennine SSSI Blanket bog is more heavily managed by burning than bog outside designated areas.

In the North York Moors, no such comparison is possible as all blanket bog is within SSSI. For the Peak District, SSSI bog appears to be less intensively managed than bog outside SSSI, although the latter only accounts for <5% of the bog in the NP. As stated above, these simple statistics may be at least partly explained by any differences in the current nature and condition of the habitats between SSSIs and non-designated sites, if the latter are less suited to

burning (e.g. if heather-dominated areas tend to be in SSSIs). It is worth noting however that reporting these statistics by heather-dominated area should account for this influence.

The more intense regime overall in the North Pennines is also reflected in burning on deep peat, with 18% of these soils showing signs of recent (<8 years) burning ($2.4\% \text{ yr}^{-1}$; Table 9) as opposed to 12% nationally ($1.5\% \text{ yr}^{-1}$; Table 6). For the NYM, this figure is more than five times higher than the national average with 23.3% burned within the last three years ($7.8\% \text{ yr}^{-1}$). In all cases burning on blanket peat is more intense than on other soil types.

Table 9. Estimates of management burning on blanket peat and other soils? within SSSI and non-SSSI sites in the North Pennines, Peak District and North York Moors.						
n.b. 'other' includes shallow peat and peat- topped soils						
	All NP/AONB		SSSI		Non SSSI	
	B Peat	Other	B Peat	Other	B Peat	Other
Heather dominated area within soil type						
<i>North Pennines¹</i>						
Annual burn %	6.6	5.9	6.8	5.9	5.8	5.5
Repeat (yrs)	15.2	17.1	14.8	16.9	17.2	18.2
<i>Peak District²</i>						
Annual burn %	4.2	3.7	4.1	3.7	5.9	3.4
Repeat (yrs)	23.7	27.0	24.3	26.8	17.1	29.3
<i>NYM³</i>						
Annual burn %	8.8	7.2	8.8	7.2	n/a	7.8
Repeat (yrs)	11.4	13.8	11.4	13.8	n/a	12.9
Total extent of soil type						
<i>North Pennines¹</i>						
Annual burn %	2.4	0.8	2.7	2.9	1.5	0.1
Repeat (yrs)	42.0	131.8	36.8	35.0	65.5	667.5

Peak District²						
Annual burn %	1.6	0.2	1.6	0.9	2.1	0.0
Repeat (yrs)	64.4	442.4	65.9	107.8	48.1	n/a
NYM³						
Annual burn %	7.8	1.5	8.0	4.8	n/a	n/a
Repeat (yrs)	12.9	66.6	12.5	20.8	n/a	n/a

¹ based on yr. 2001/2003 imagery ² based on yr. 2005 ³ based on yr. 2009

3.4 Burning as practiced on specific habitat and soil type among habitats and soil types

Some 38% of all burning recorded in the 208 km² national sample occurred on bog compared to 60% on upland heath. The more localized sampling indicates far higher proportions of burning on bog in the Peak District (47%) and north Pennines (60%). Despite the Defra ‘code’, burning on bog is therefore a very important component of overall burning (Table 10). The effects of the Code, consents from and agreements with NE would appear to be limited since 29% of all burning that occurred in England over the 8 years to 2000 was conducted on bogs with SSSI status, more than occurs *in total* outside SSSI. These figures do need to be interpreted cautiously, since non-designated sites may be less suited to burning management.

	heather on bog (%)	all burning on bog (%)	all burning on SSSI bog (%)	Bog burned annually (km ²)
National sample	39.3	38.5	29.2	* 43.9
N Pennines AONB	56.8	60.0	48.8	16.3
Peak District NP	47.4	47.4	42.3	3.1
NYM NP	3.3	3.9	3.9	0.9

* Estimated from 2% sample (see Yallop *et al.*, 2006)

In the national sample, some 46% of burning is located on deep peat, and 36% of all burning is located on deep peat within SSSI boundaries (Table 11). More than half of all burning (60-65%) within the North Pennines and Peak District occurs on blanket peats in SSSIs.

Table 11. Burning on blanket peat as a % of all burning

	heather on blanket peat (%)	all burn on blanket peat (%)	burn on SSSI blanket peat (%)	burn on blanket peat annual (km ²)
National sample	47.8	45.8	35.8	* 52.2
N Pennines AONB	62.3	65.4	53.6	17.8
Peak District NP	56.6	59.8	54.8	4.0
NYM NP	11.3	13.3	0	3.2

* Estimated from 2% sample (see Yallop *et al.*, 2006)

4 Discussion

4.1 Methodological issues and habitat definitions

There would appear to be a number of technical issues with regard to at least some of the current Natural England upland habitat inventories. Differentiation of bog from upland heath in the datasets used here was at times poor, with numerous areas being 'doubly accounted' for or classified as both habitats. This raises questions about the accuracy of one or both datasets as well as confusion in the criteria used to map habitats. Part of this is undoubtedly the 'weighting' given to contemporary survey data over the ecological history of a site. The extant vegetation present at most upland sites will have been modified by land use and management (including burning, drainage and grazing) from that which formed extensive areas of blanket peat over thousands of years. It is likely therefore that definition of habitats undertaken on the ground under-estimates the historical extent of blanket bog by classifying degraded forms of this habitat as forms of upland heath. An example of this would be where heath-type vegetation like M15 *Scirpus cespitosus-Erica tetralix* wet heath occurs on deeper peats, especially since NVC (National Vegetation Classification; Rodwell, 1991) does not explicitly use substrate type as determinants (although peat depth is incorporated to some extent in JNCC's NVC field guide to mires and heaths (Elkington *et al.*, 2001)). If the soil map can be relied upon, then this is the best measure of the *historical* extent of blanket bog, even if much of that extent is no longer in an active phase of peat accumulation. In fact both blanket bog and upland heath inventories are claimed to incorporate soil data (as stated in associated metadata), however, the extent to which this has succeeded must be questioned. A comment in the metadata that: '*historically, the biggest problem has been establishing the divide between blanket bog and heathland...the use of the soil map has provided a way around this problem*', would appear unduly optimistic based on the data used here.

It is also known that the blanket bog and upland heath inventories have been compiled from a

variety of sources with different resolutions and methods and therefore the definition of blanket bog used in the mapping process is inconsistent. The difficulty of a precise definition of blanket bog has been commented on previously by Glaves & Haycock (2005) and is a significant problem. The UK BAP's (2007) definition of blanket bog, for example, excludes 'areas which no longer support [blanket bog] vegetation' although the recently revised priority habitat definition includes them (GeoData Institute, 2011). On the other hand, in their submission to the Burning Review Science Panel, Natural England took the view that '*there should be a presumption that degraded bogs can be restored until the contrary can be demonstrated*', and degraded bogs are included as part of blanket bog habitat inventory (as stated in the attached metadata).

There is clearly much further work to be undertaken in refining the upland habitat inventories some of which we are aware is currently underway. Certainly areas of overlap between classes are unacceptable and should be rectified as a priority. The definition of blanket bog habitat as mapped needs a more precise formulation to prevent future confusion. Natural England (2010) gives an estimate of the extent of blanket peat that exceeds that recorded in the digital blanket bog inventory by $>1000 \text{ km}^2$.

These difficulties within the present digital datasets used in this project mean that some caution should be taken in interpreting the area statistics presented.

4.2 Proportion of different habitats and soils managed by burning: Evidence of habitat status.

Some 4.5% of ericaceous upland heath is burnt each year on a national scale compared to 6.2% in the North Pennines, 4.2% in the Peak District and 7.5% in the North York Moors, showing that the North Pennines and particularly the North York Moors are more intensively managed than the 'average'. Such an overall figure would not be considered too intense for upland heath habitat *if it was evenly distributed*. However as seen in ENRR 667, this is unlikely to be the case (see below). More realistic estimations of return periods as they occur on the ground would require fine-scale statistical analysis.

The overall estimate that 3.8% of the heather-dominated areas of blanket bog within England is being burned each year is not actually far from that occurring on upland heath habitat, where it is 'expected'. This figure is the very close to that obtained for deep peat substrates (3.7%); if it is assumed that errors in classification of bog and deep peat inventories are

symmetrical, it is likely that this figure represents a good estimate of what is actually occurring on the ground. It would be wrong to conclude however that this equates to a return period approaching 27 yrs. Such estimates assume the entire inventory of the habitat is under the same management, but as has been shown in Yallop *et al.* (2006b), management is far from evenly distributed. Histograms of management regimes are positively skewed with a considerable number of intense regimes, a long tail of lightly-managed sites, and a large quantity classified as 'unmanaged', all contributing to this overall average. Hence conclusions as to the impacts or otherwise of repeat times from these data would be unsound. The figure of an average of 8.5% bog burned each year in the North York Moors is striking, despite the fact that bog makes up a relatively small area of this national park. 6.7% of bog in the North Pennines AONB is burnt each year, actually higher than that recorded on upland heath (6.2%). The distinction between upland heath and bog in the national parks and AONB is less clearly drawn than nationally (Tables 4, 7). It is not clear why this should be the case, but it should be noted that the national figure is an estimate based on a c.2% sample which, although offering wide coverage, comprises a much lower total area than either of the national parks or the AONB. The statistics reported here cover nearly a decade, which leaves room for possible changes in management over this period as reasons for these differences.

It is clear that habitats within SSSIs are being burned more intensively than non-designated land, both nationally and on a regional scale in the North Pennines and North York Moors. This is understandable for upland heath, where the mosaic structure of different-aged stands of heather is a conservation target. However, in the North Pennines this trend is also apparent in blanket bog habitat and this should be a cause for concern.

It would appear that the division between bog and heath set by remote sensing or field surveys is not related to what burning management happens on the ground. There is a very strong correlation between the amount of burning on the bog element of North Pennine SSSIs and the upland heath element of those SSSIs, where both habitats occur ($n=18$, $r=0.827$, $p<0.001$). In other words the burning undertaken by land managers appears to consider each moor or SSSI as a whole, and effectively disregards habitat distinctions (data from Yallop *et al.*, 2006b, Table 3.3).

It is also worth noting that the heathland inventory includes wet heath, which like blanket bog has a presumption of protection under the Heather and Grass Burning Code. Wet and dry heath were not distinguished in this study, but it would be worthwhile to establish whether wet heath is less intensively managed than dry heath.

4.3 Distribution of burning practice among different habitats and soils: Evidence for compliance with ‘burning code’.

The Heather and Grass Burning Code includes ‘peat bog and wet heathland’ as sensitive areas where there should be a strong presumption against burning (except where in line with a management plan agreed with Natural England). It also states that burning on SSSIs requires consultation with the local office of Natural England. The figures presented here show that there is a major disparity between the intentions of the Code and the use of fire on the ground. It would not be an exaggeration to say that most managed burning (60-67%) in the North Pennines contravenes the Code in this respect, while at the national scale the estimate is that 35-45% of all burning does so (the range is due to whether burning on bog (lower figure) or deep peat (higher figure) is considered). 60% of burning in the Peak District is taking place on deep peat. More burning occurs on bog within SSSIs than occurs in total *outside* SSSIs, a statistic which if we accept the findings of recent reviews (Tucker, 2003; Stewart *et al.*, 2004; Glaves & Haycock, 2005) indicates that far from being protected, bogs are currently being systematically damaged. Part of the explanation may be, as stated above, that divisions between habitats are not obvious on the ground, especially where heather is dominant on deep peat, and that a single burning prescription is being carried out which more suits heath than bog.

4.4 Loss of bog habitat

It is perhaps surprising that *just under half* (1197 km²) of the total (2902 km²) of mapped blanket peat (NSRI digital data) is overlain by habitat not currently regarded as bog. As these deep peats must originally have been derived from bog habitat this is an striking figure.

While some of this disparity must arise from errors in reconciliation of field survey data with soil maps to ascertain existence of blanket bog as suggested above, it is also likely to be, a real measure of the extent of lost or degraded bog habitat in England.

Not only are bogs of biodiversity interest they are assumed to provide a plethora of ecosystem services. *That nearly half of this resource is already degraded enough to no longer be classified as bog habitat would seem to be a sobering observation. It almost certainly indicates a significant compromising of the ecosystem services, in particular carbon sequestration, which these areas are usually presumed to provide.*

It does perhaps need greater recognition that the occurrence of blanket peat indicates nothing more than that carbon storage occurred in the past; it is only the presence of Sphagnum-rich bog vegetation today that is any measure of current sequestration.

When an accurate inventory of blanket bog is established, this should also include an inventory of the *historic* extent of blanket bog. It is likely that the disparity between these two inventories would serve as a stimulus to conservation efforts. Further, an inventory of *Sphagnum*-dominated bog would illustrate how little of what remains of the blanket bog resource is actively accumulating peat. The comparison of these three inventories would be a useful conservation tool.

4.5 Summary and concluding remarks.

It is apparent from the data presented here that burning of bog habitat is a widespread and significant activity, nationally approaching levels occurring on upland heath. In the North Pennines AONB and North York Moors NP the burning of bog is occurring at a greater intensity than on upland heath. It would be logical to interpret these figures as an indication that a voluntary prohibition on burning within bog habitat is ineffective.

As all burning activity within SSSI has to be consented by Natural England and, as burning of bog is not recommended within the 'code', it is not clear why such high levels of burning management should be occurring on blanket bog. What is clear is that widespread burning is occurring on blanket bog where consents and/or management agreements must have been agreed with Natural England. It would appear that such consents and agreements are either falling short of what is required to protect blanket bog or are not simply not being enforced.

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